

Spring 2019 IceBridge Arctic Flight Plans  
22 March 2019 Draft

*compiled by*

John Sonntag

# Introduction to Flight Plans

This document is a translation of the NASA Operation IceBridge (OIB) scientific objectives articulated in the Level 1 OIB Science Requirements, at the January IceBridge Arctic planning meeting held at NASA GSFC, through official science team telecons and through e-mail communication and iterations into a series of operationally realistic flight plans, intended to be flown aboard NASA's P-3 Orion aircraft. Following the December-January partial U.S. Government shutdown, the new revised OIB spring schedule begins in early April and ends in late May 2019. The material is shown on the following pages in the distilled form of a map and brief text description of each science flight.

For each planned mission, we give a map and brief text description for the mission. The missions are planned to be flown from Thule and Kangerlussuaq, Greenland. The previously-planned Fairbanks-based flights were removed as a result of the shutdown. A careful reader may notice that some of the mission maps in the main part of the document highlight flightlines in green, yellow, and red colors, while other only show the black lines. The colors are a refinement added to the flight plans at a late stage of design which help the field team navigate the aircraft properly to achieve specific science goals. The colors represent the degree of “straightness” of each flight segment, where straight segments are steered using an automated technique and curved sections using a specialized manual method. Not all of the flight plans shown here have necessarily reached that mature stage of design.

In fact, as a general rule the flight plans depicted here are all at varying stages of completeness. For each mission we note “Remaining Design Issues” to be resolved, if any exist. In most cases these are minor. ICESat-2, CryoSat-2 and Sentinel 3a underflights are a major exception, since these have to be re-planned for each potential flight day (for sea ice) or within a window of several potential flight days (for land ice). Sea ice camp/site overflights are also an exception, since these move with the motion of the ice, unless they are situated on shore-fast ice.

In the past OIB has collected science data during transit flights between Thule and Kangerlussuaq. For 2019, if weather permits on the day of the transit, we will attempt to fly the “Sea Ice – Baffin Bay” mission, targeting a combination of low-latency spacecraft ground tracks. This is a short mission, adding only about one hour to the direct transit time. A short data-collecting mission such as this one should still allow the field team sufficient time to load the aircraft in Thule, unload it in Kangerlussuaq, and set up there as well.

Note that this document shows 49 planned land ice and 9 planned sea ice missions (one of which is a placeholder for up to five), which is more than we expect to fly this year. The extra flight plans give us operational flexibility to fly as much as possible, and scientifically productive, while we are in the field. The entire suite of 49 flight plans is depicted in the introductory material following this text.

Each flight has a priority assigned to it by the OIB science team, either high, medium or low, and these are listed below with each mission. Both land and sea ice flights include some designated “baseline”, or highest, priority, which is reserved for flights intended to be flown each year. There are six such flights for land ice and five for sea ice. The land ice team instituted a refined strategy starting in the 2014 season, which emphasized the need to conduct comprehensive  $dh/dt$  monitoring over a multi-year time scale. We continue this strategy for 2019. These flights are labeled as such in the text descriptions. In general the flights in this category which have not been flown recently are prioritized highest, while those flown last year are prioritized lowest. These priorities will be revisited each year, with the goal being to ensure all of these flights will be flown on a rotating basis. This repeat strategy

is depicted in the introductory material following this text, Several new flights are also shown, as well as several flights designed for previous years but never flown.

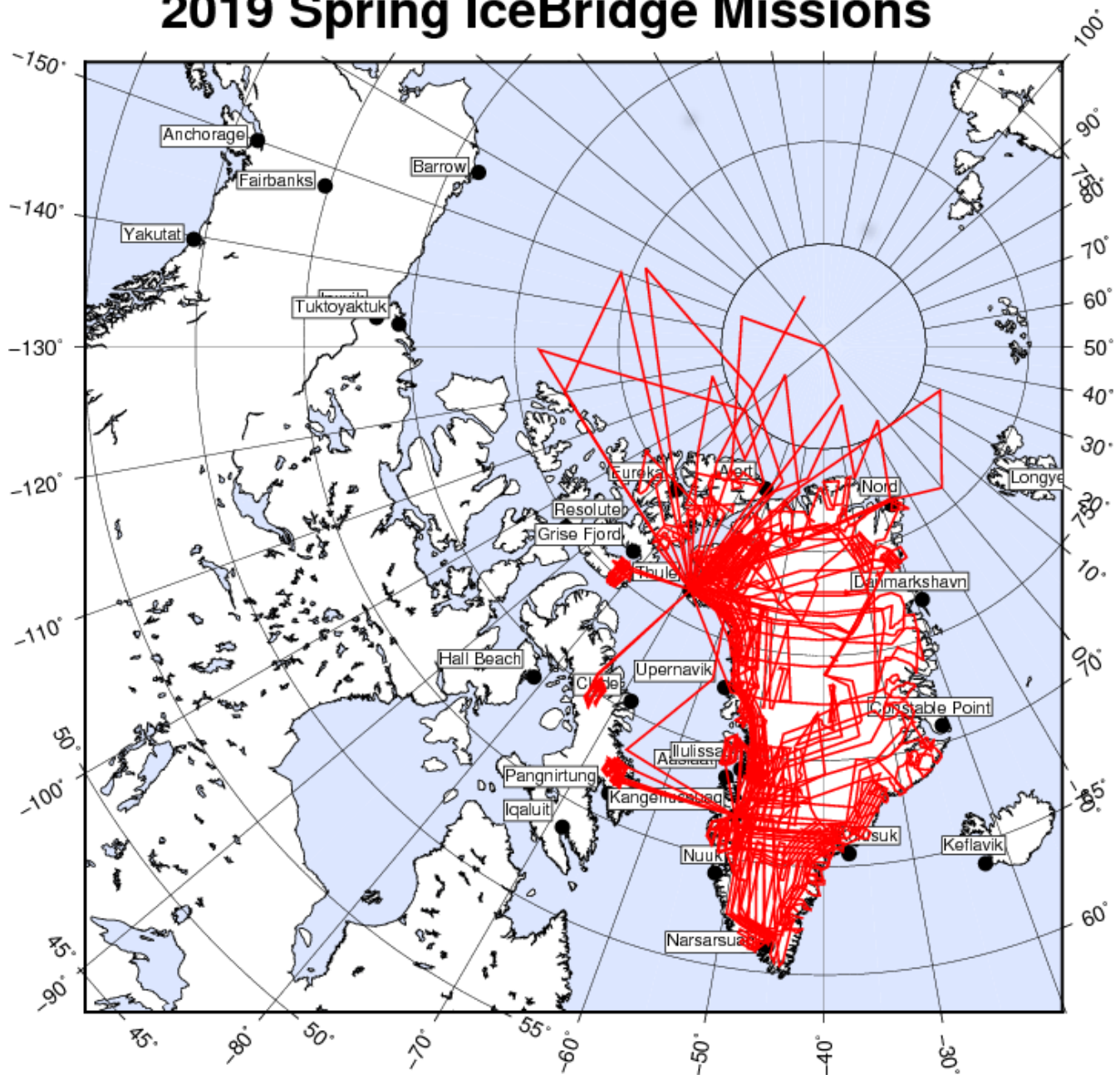
### **Additional notes on flight prioritizations**

Due to the recent launch of ICESat-2 and OIB's role in performing the "bridge" function to the new spacecraft, flight prioritizations for 2019 contain more nuance than in prior years. Here we spell out the additional considerations relating to flight priorities.

For sea ice, we intend to fly ten missions. Of these, we plan for five of them to be classical "OIB flights", and five to be dedicated ICESat-2 low-latency underflights (for which "Sea Ice Arctic Ocean" is the placeholder). If we substitute nearby ICESat-2 low-latency lines into classical OIB flights, we might count that flight in both categories. Also, we hope to dedicate portions of some of the flights to low-latency underflights of CryoSat-2, Sentinel-3a, and Sentinel-3b.

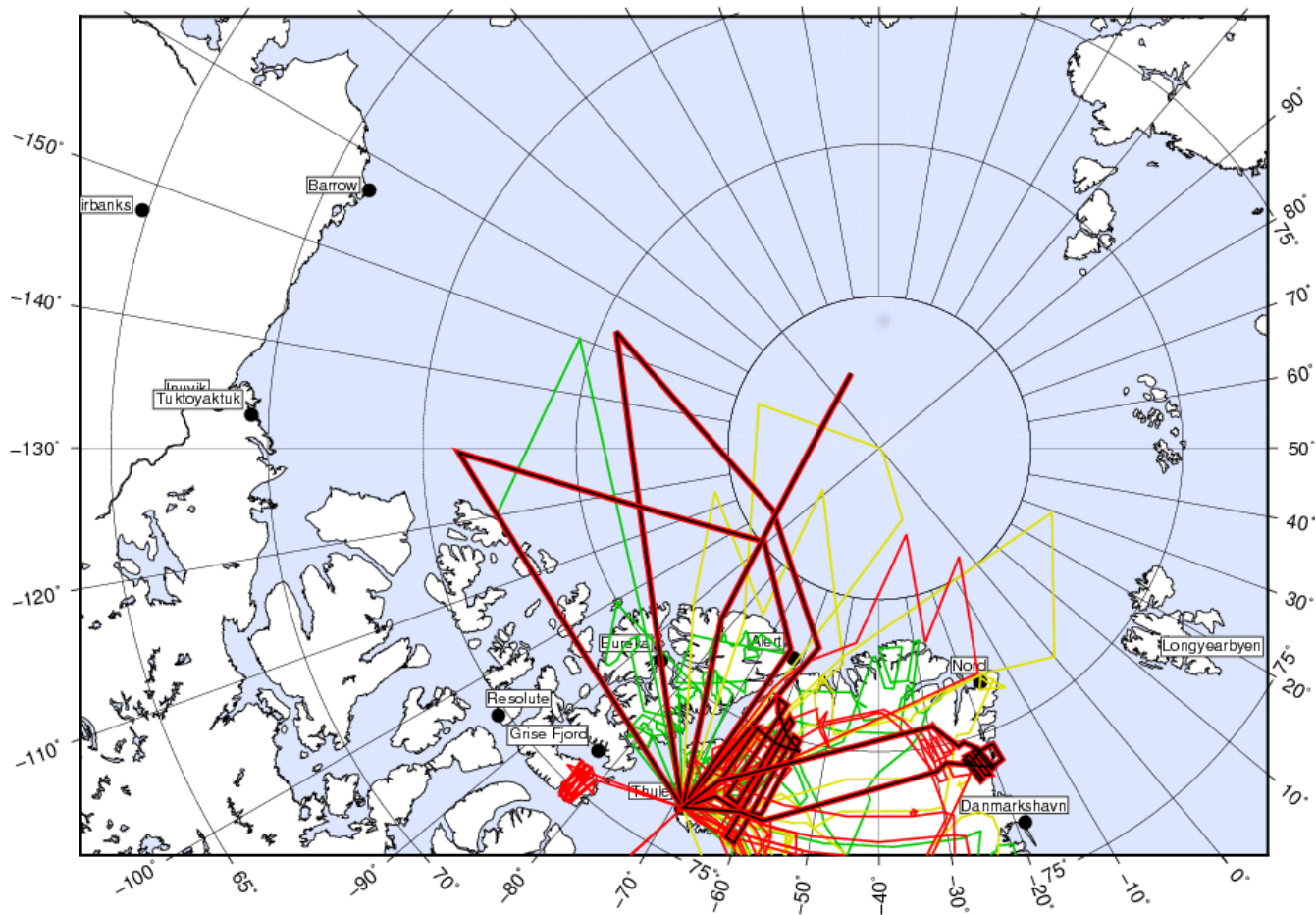
For land ice, for the most part, the priorities listed for each mission in this document tell the full story. The only exception is for a group of flights designed to assist the ICESat-2 community in improving the geolocation of its laser footprints. These six missions are IS-2 Devon, IS-2 Barnes, IS-2 Penny, IS-2 Peary Land, IS-2 Disko/Umanaq, and IS-2 Sukkertoppen. While these six missions each have the usual priorities assigned to them, the overriding priority regarding these is to fly any two of them during the 2019 spring campaign.

# 2019 Spring IceBridge Missions



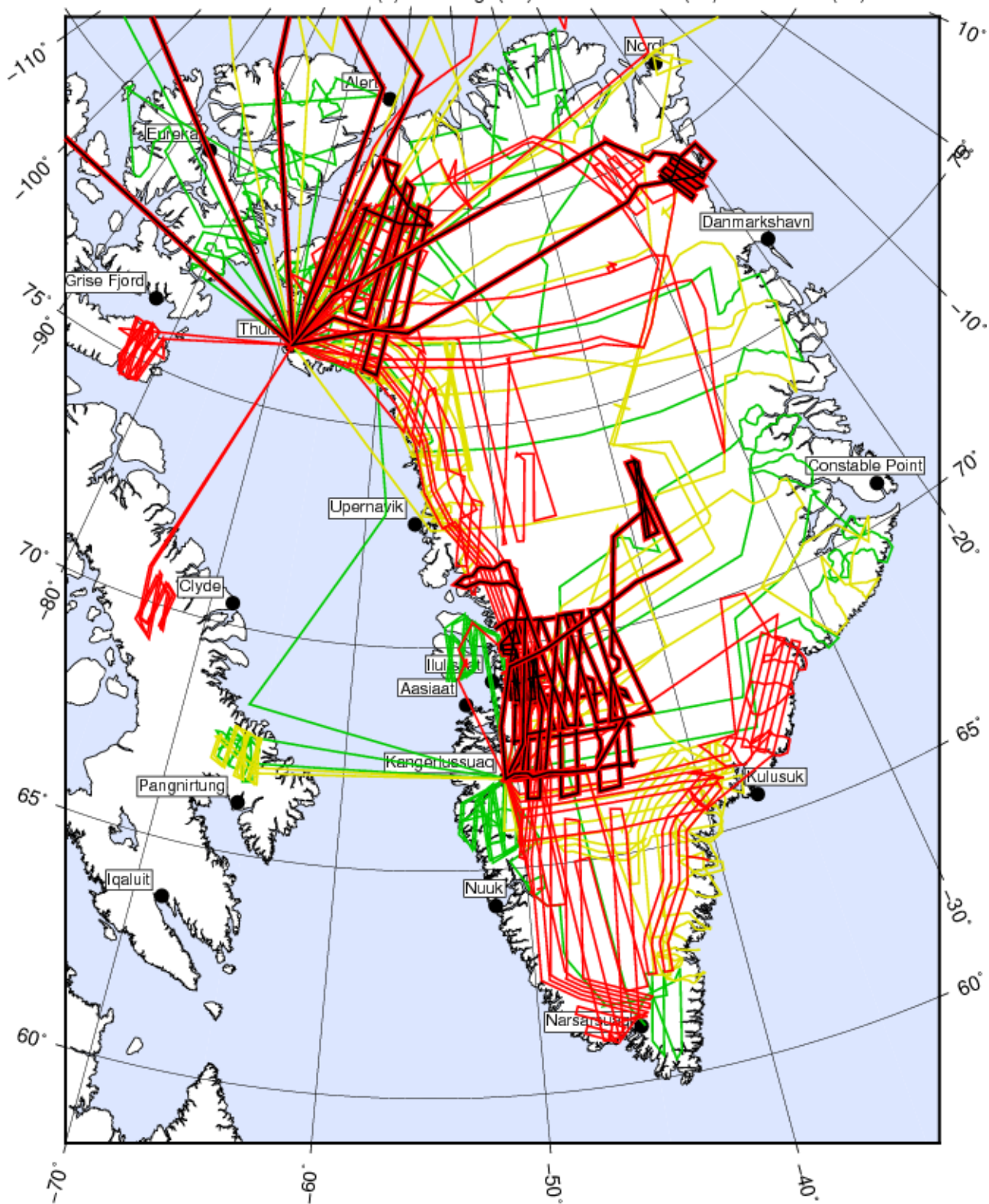
# Prioritized Spring 2019 OIB Sea Ice Missions

Thick Red/Black:Baseline(5) Red:High(4) Yellow:Medium(3) Green:Low(2)



# Prioritized Spring 2019 OIB Land Ice Missions

Thick Red/Black:Baseline(6) Red:High(17) Yellow:Medium(13) Green:Low(13)



# Sea Ice – Laxon Line / Thule

This mission is a near-exact repeat of similar missions flown each year of OIB beginning in 2009. In addition to Level-1 Requirements SI1 and SI2, the flight addresses sea ice level 1 baseline requirement SI3a by providing data on the thickness gradient and distribution of perennial and seasonal ice across the Arctic Basin. For 2019 this mission is configured as a round-trip from Thule, with a direct return from the western end of the line at high altitude.

**Flight Priority:** baseline

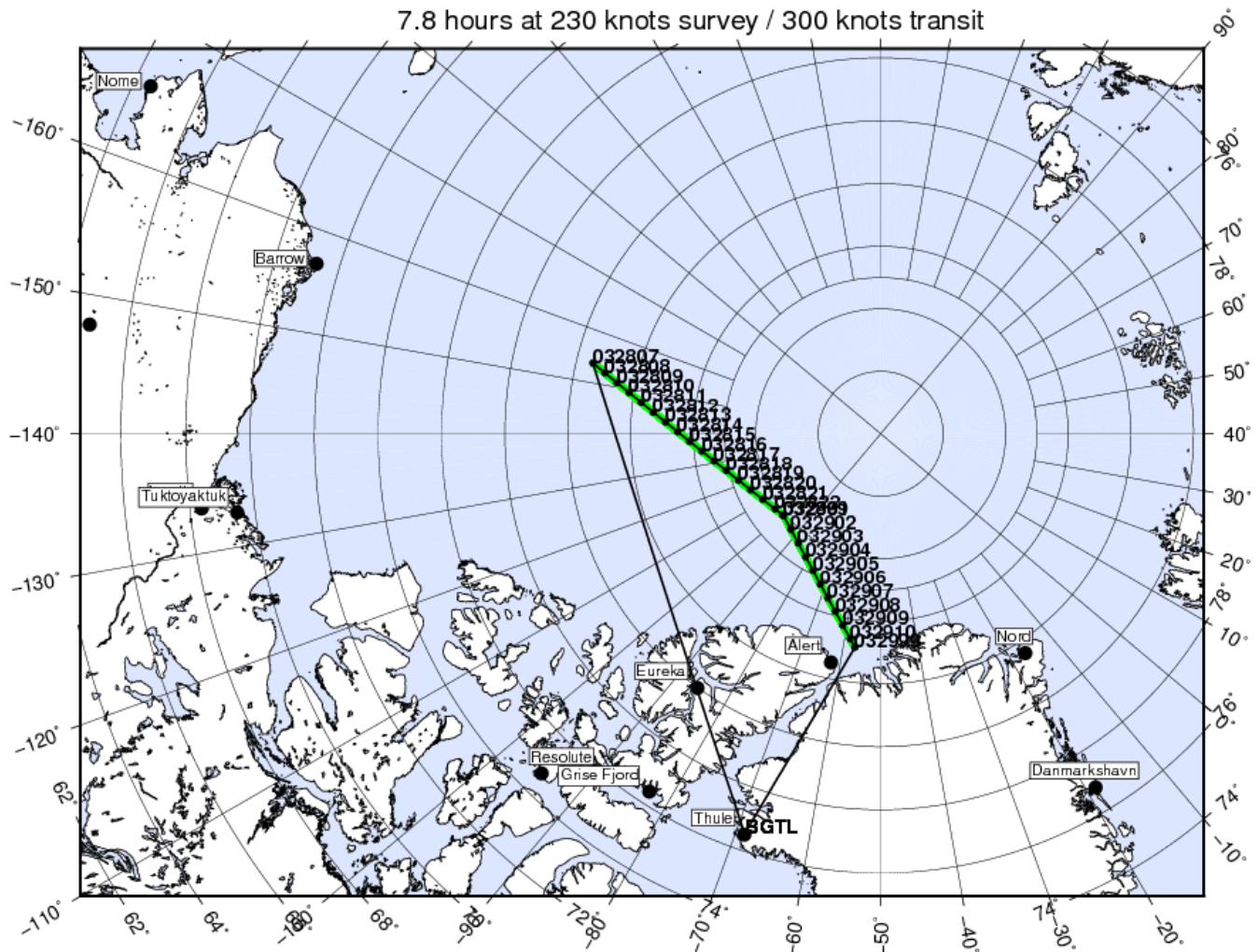
**ICESat Tracks:** 0329,0328

**Last Flown:** 2018

**Remaining Design Issues:** none

## Sea Ice – Laxon Line

7.8 hours at 230 knots survey / 300 knots transit



# Sea Ice – South Basin Transect / Thule

This mission is a repeat of missions flown each year of OIB beginning in 2009. For 2016 the portion of this flight north of Ellesmere Island was slightly modified to improve the distribution of coverage in that area. In addition to Level-1 Requirements SI1 and SI2, it addresses sea ice level 1 baseline requirement SI3a by providing data on the thickness gradient and distribution of perennial and seasonal ice across the Arctic Basin. For 2019 this mission is configured as a round-trip from Thule, with a direct return from the western end of the line at high altitude.

**Flight Priority:** baseline

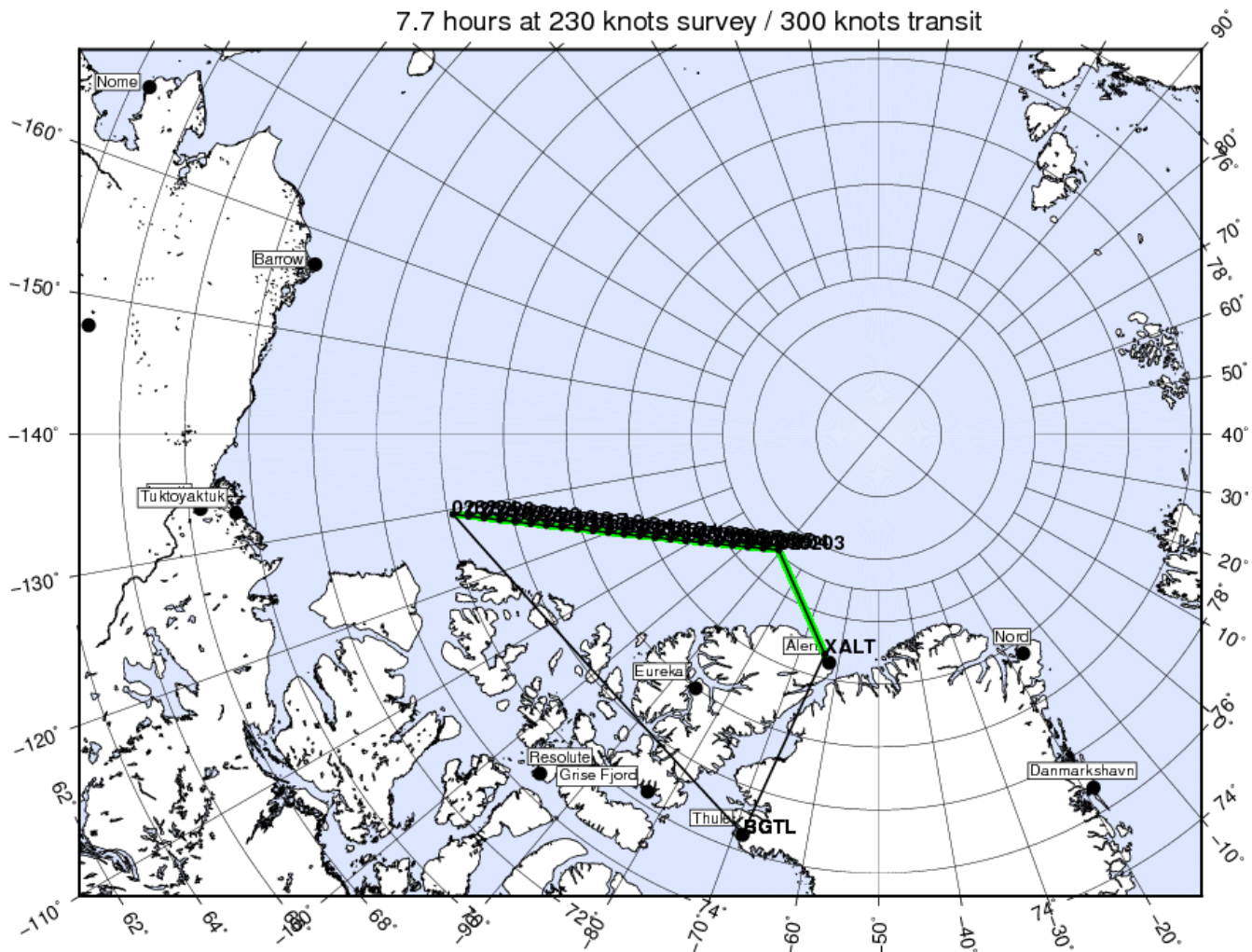
**ICESat Tracks:** 0282

**Last Flown:** 2018

**Remaining Design Issues:** none

## Sea Ice – South Basin Transect

7.7 hours at 230 knots survey / 300 knots transit



# Sea Ice – South Canada Basin / Thule

This mission is designed to enhance the sampling in the large region between the North Basin Transect and the Beaufort-Chukchi Diamond that had been poorly sampled by OIB prior to 2012. In addition to Level 1 Requirements SI1 and SI2, the mission addresses sea ice level 1 projected requirement SIP2 by extending the baseline observations into other regions of the Arctic Basin.

**Flight Priority:** low

**ICESat Tracks:** none

**Last Flown:** 2017

**Remaining Design Issues:** none

## Sea Ice – South Canada Basin

7.6 hours at 230 knots survey / 300 knots transit



# Sea Ice – Zigzag West / Thule

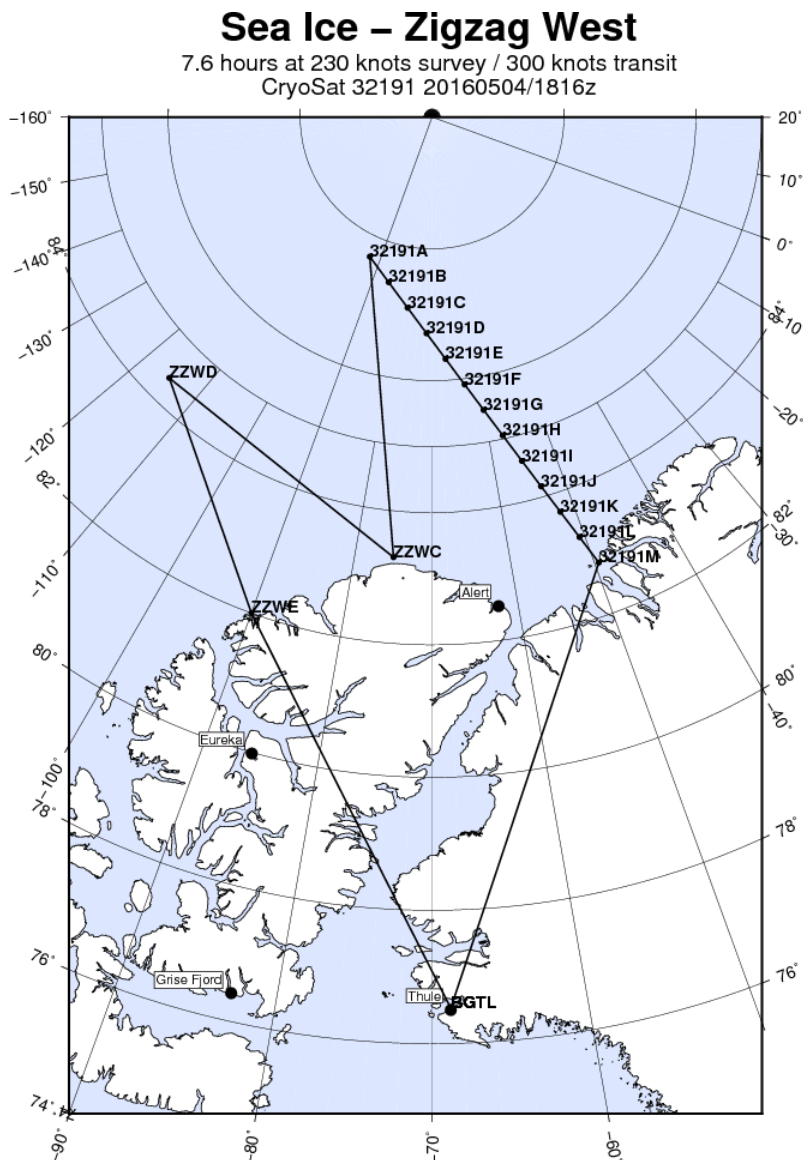
This mission is a repeat or near-repeat of an OIB flight first flown in 2010. It is intended to sample the thick multi-year ice near the Ellesmere coast as well as the gradient to thinner ice closer to the pole. A nearby ascending CryoSat-2 ground track may be substituted for one of the tracks shown below if a nearly contemporaneous one is available when this flight is conducted. In addition to Level 1 Requirements SI1 and SI2, the mission addresses sea ice level 1 baseline requirement SI3b by sampling thick multi-year ice near the northern coast of Ellesmere Island and the poleward gradient towards thinner ice.

**Flight Priority:** medium

**ICESat Tracks:** none

**Last Flown:** 2017

**Remaining Design Issues:** none



# Sea Ice – IS-2 Arctic Ocean / Thule

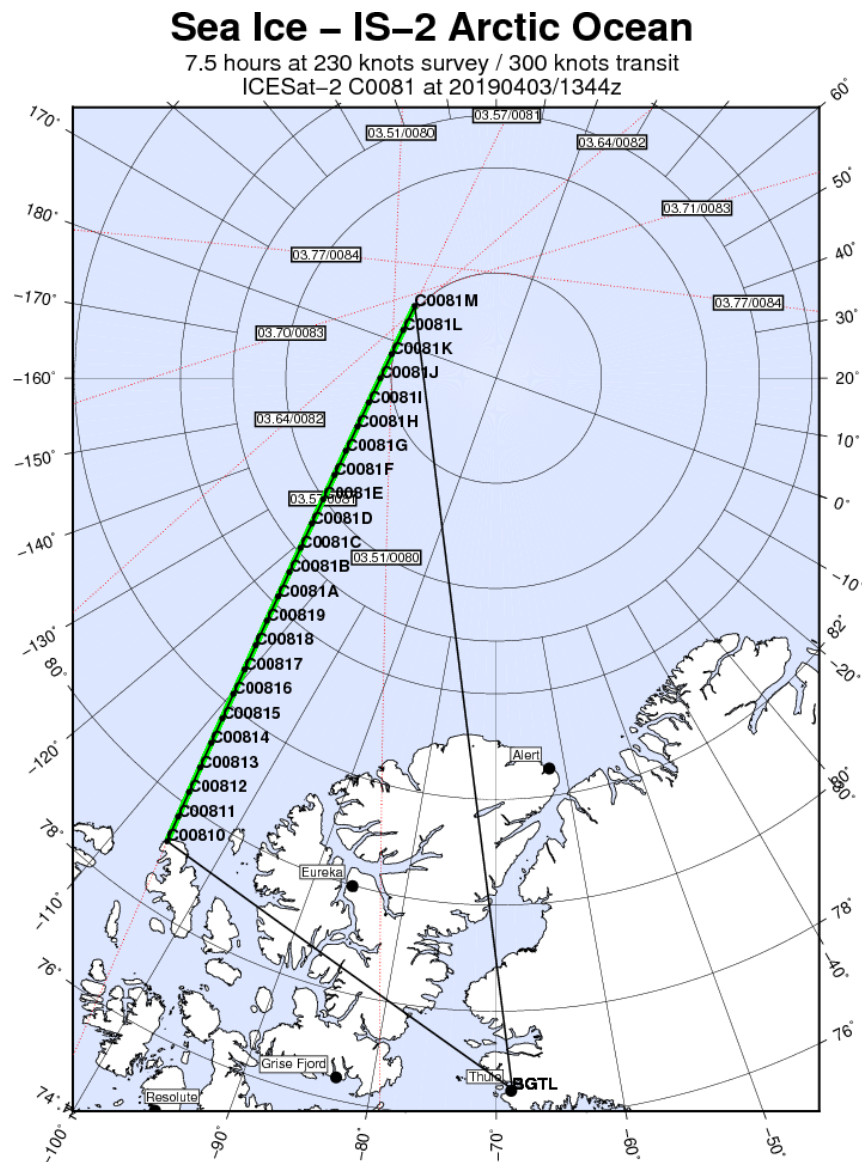
This new flight for 2019 flies out-and-back along a single ICESat-2 ground track, selected and timed so that our aircraft and the spacecraft fly the track as closely as possible in time, and also with the track drift-corrected according to winds measured from the aircraft. The particulars of the technique we will use to fly the track will depend on knowledge of ICESat-2's pointing accuracy just prior to the time of this flight. Options include out-and-back along the same or parallel and offset lines, varying the altitude of one or both lines, or even a four-segment line. The general idea is to obtain a composite swath wide enough to capture any likely pointing offset of the spacecraft. See Appendix D for more details on the design of these flights.

**Flight Priority:** three baseline, two high

**IceSat-2 Tracks:** TBD

**Last Flown:** new flight

**Remaining Design Issues:** see above



# Sea Ice – North Pole Transect / Thule

This mission is a repeat or near-repeat of an OIB flight flown every years since 2013. The intention is to sample ice in the vicinity of the Pole and also the gradient of that ice between the Pole and Ellesmere Island. This area had been undersampled by OIB prior to 2012. A nearby descending CryoSat-2 ground track may be substituted for one of the tracks shown below if a nearly contemporaneous one is available when this flight is conducted. In addition to Level-1 Requirements SI1 and SI2, this mission addresses sea ice level 1 projected requirement SIP2a by extending sea ice baseline observations to the North Pole region, and sea ice level 1 baseline requirement SI4 by conducting a sampling mission that is time-coincident with a CryoSat-2 track.

**Flight Priority:** medium

**ICESat Tracks:** none

**Last Flown:** 2018

**Remaining Design Issues:** none



# Sea Ice – Zigzag East / Thule

This mission is a repeat or near-repeat of an OIB flight flown in prior years. It is intended to sample the thick multi-year ice near the Greenland coast as well as the gradient to thinner ice closer to the pole. The eastern- and westernmost gradient lines are IceSat-2 ground tracks. In addition to Level 1 Requirements SI1 and SI2, the mission addresses sea ice level 1 baseline requirement SI3b by sampling thick multi-year ice near the northern coast of Greenland and the poleward gradient towards thinner ice.

**Flight Priority:** high

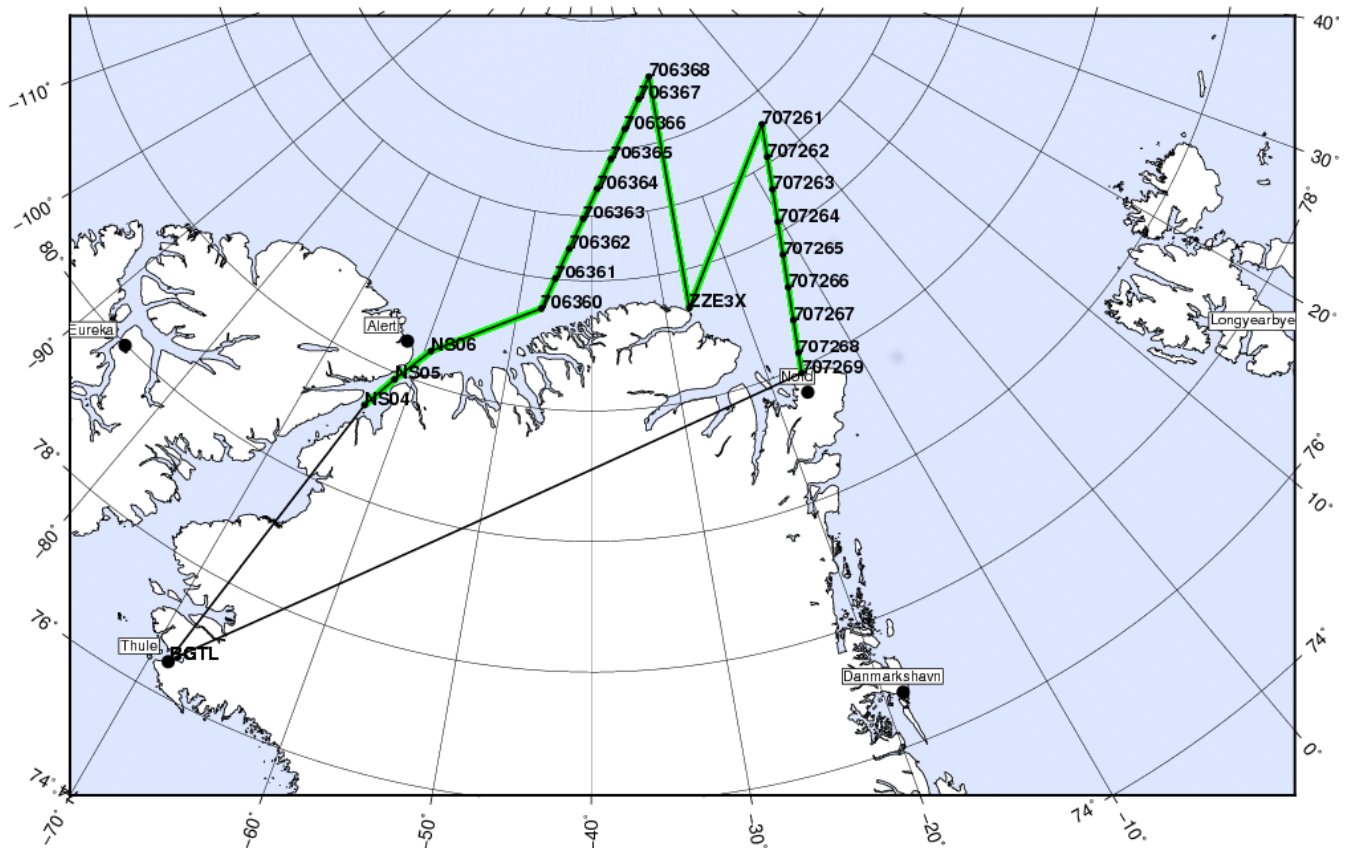
**ICESat Tracks:** none

**Last Flown:** 2018

**Remaining Design Issues:** substitute low-latency IS-2 line in east if possible

## Sea Ice – Zigzag East

7.7 hours at 230 knots survey / 300 knots transit



# Sea Ice – Nansen Gap / Thule

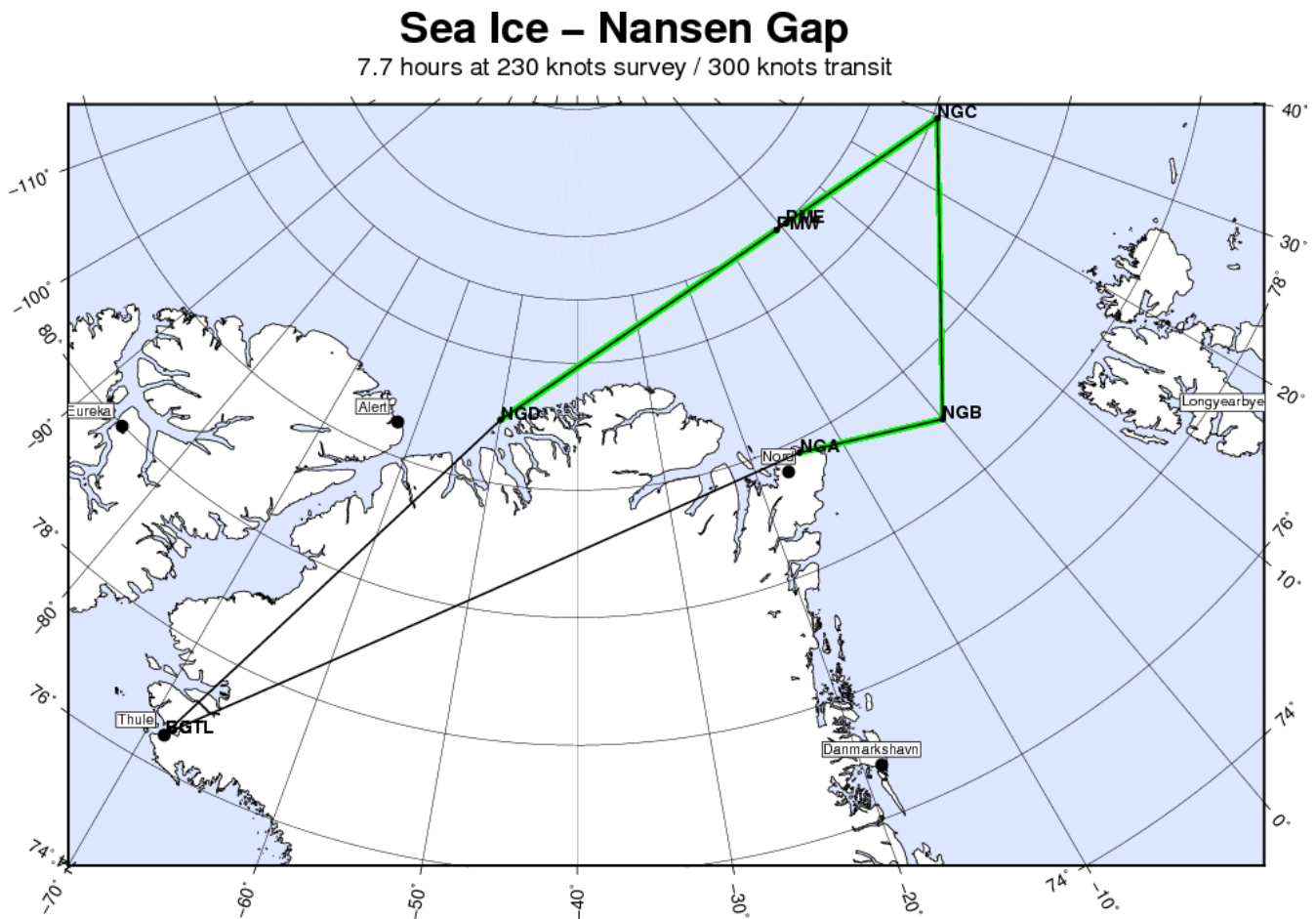
This is a modified version of the Fram Gateway missions flown in the earlier years of IceBridge. It differs from them in that it transits to and from the area of the Fram Strait at high-altitude, leaving more time to sample ice farther north and east than in prior years. In addition to Level 1 Requirements SI1 and SI2, this mission addresses sea ice level 1 baseline requirements SI3c and d by sampling sea ice north of Fram Strait.

**Flight Priority:** medium

**ICESat Tracks:** none

**Last Flown:** 2018

**Remaining Design Issues:** none



# Sea Ice – Baffin Bay / Thule to Kangerlussuaq

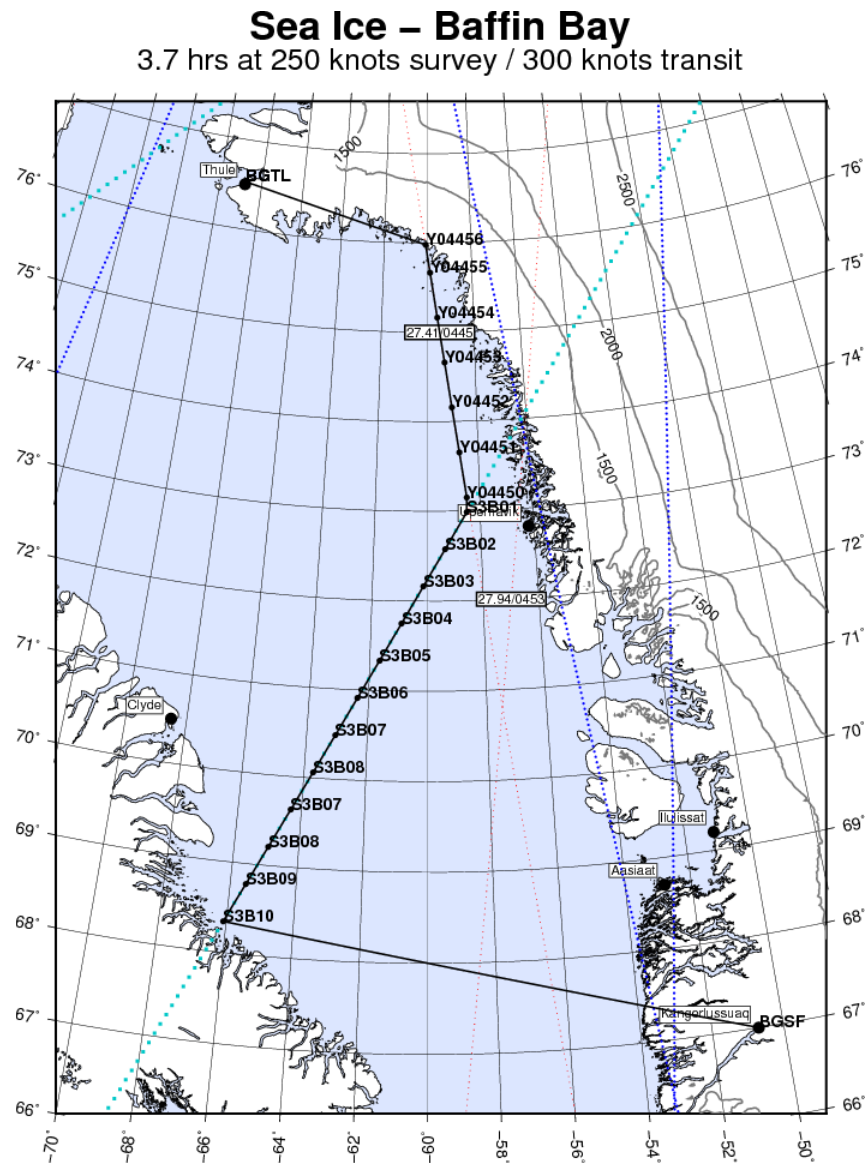
This is a new mission for 2019, designed to occupy any, or a combination of, low-latency satellite ground tracks for ICESat-1, CryoSat-2, Sentinel-3a, or Sentinel-3b in Baffin Bay. These tracks will be selected opportunistically for the day of the project's reposition from Thule to Kangerlussuaq, if weather permits.

**Flight Priority:** low

**ICESat Tracks:** TBD

**Last Flown:** new flight

**Remaining Design Issues:** replace placeholder spacecraft tracks with real ones for day of transits



# Land Ice – North Ellesmere 01 / Thule

This mission is designed as part of OIB's multi-year dh/dt repeat strategy, and based both on the ATM surveys of the Canadian ice caps dating back to 1995, and to flightlines designed with Dave Burgess and Martin Sharp as part of a CSA/NASA agreement in 2014 and flown that same year. This mission concentrates on the northern Ellesmere ice field and on the Agassiz Ice Cap in east-central Ellesmere. For the northern ice field, we fly a historical ATM line traversing the ice from southwest to northeast plus centerlines of the major glaciers draining the ice field. We also fly a number of such glaciers on Agassiz, along with a pair of historical ATM lines.

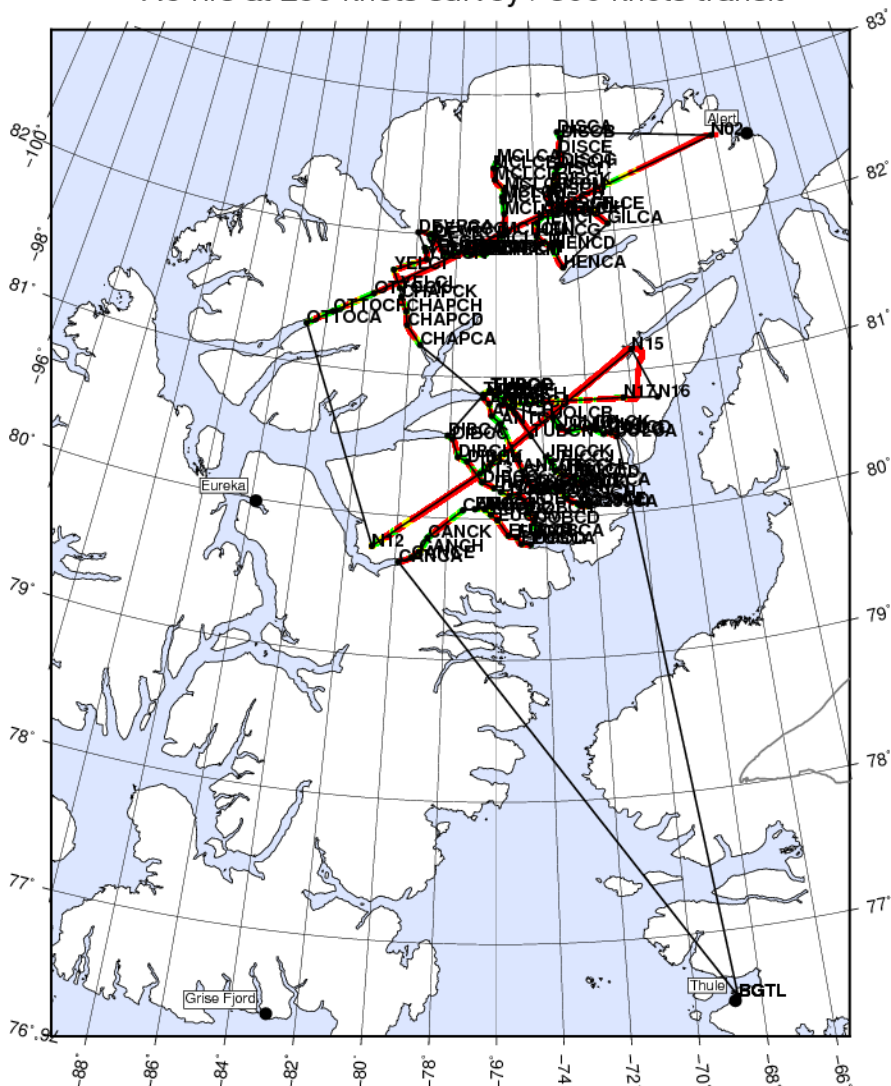
**Flight Priority:** low (multi-year repeat flight)

**ICESat Track:** none

## Last Flown: 2017

**Remaining Design Issues:** none

**North Ellesmere 01**  
7.5 hrs at 250 knots survey / 300 knots transit



# Land Ice – South Ellesmere 01 / Thule

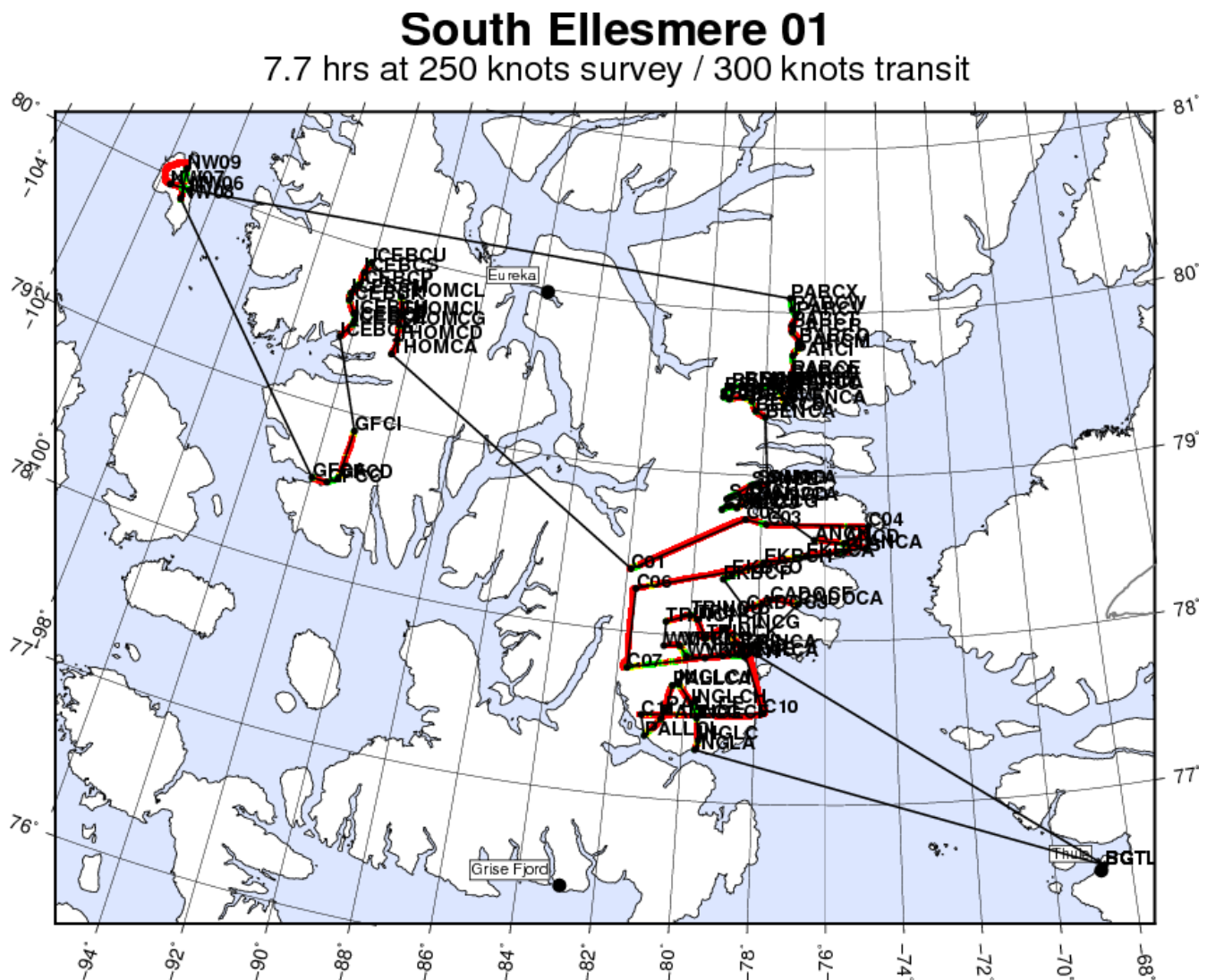
This mission is designed as part of OIB's multi-year dh/dt repeat strategy, and based both on the ATM surveys of the Canadian ice caps dating back to 1995, and to flightlines designed with Dave Burgess and Martin Sharp as part of a CSA/NASA agreement in 2014 and flown that same year. This mission surveys the Prince of Wales ice cap on southeastern Ellesmere, including a number of glacier centerlines from the 2014 effort and four transects from the historical ATM lines, three glacier centerlines on the southern Agassiz ice cap, three on Axel Heiberg Island, and two crossing tracks on the Meighen Island ice cap.

**Flight Priority:** low (multi-year repeat flight)

**ICESat Track:** none

## Last Flown: 2017

**Remaining Design Issues:** none



# Land Ice – ICESat-2 Devon / Thule

This is a new mission for 2019, primarily designed to sample the left and right beam pairs of ICESat-2 over the Devon Ice Cap and nearby undulating bare rock (likely to be snow-covered in April). The intention is to validate the geolocation of ICESat-2 footprints. The pattern of ICESat-2 ground tracks is nearly repeated, targeting the left beam pair on one pass and the right pair on the other. We validate range biases on the center beam pair during other missions. We also re-fly a pair of historical OIB lines crossing the ice cap, and one of the new IS-2 lines is a very close match to a 2012 CryoSat-2 line.

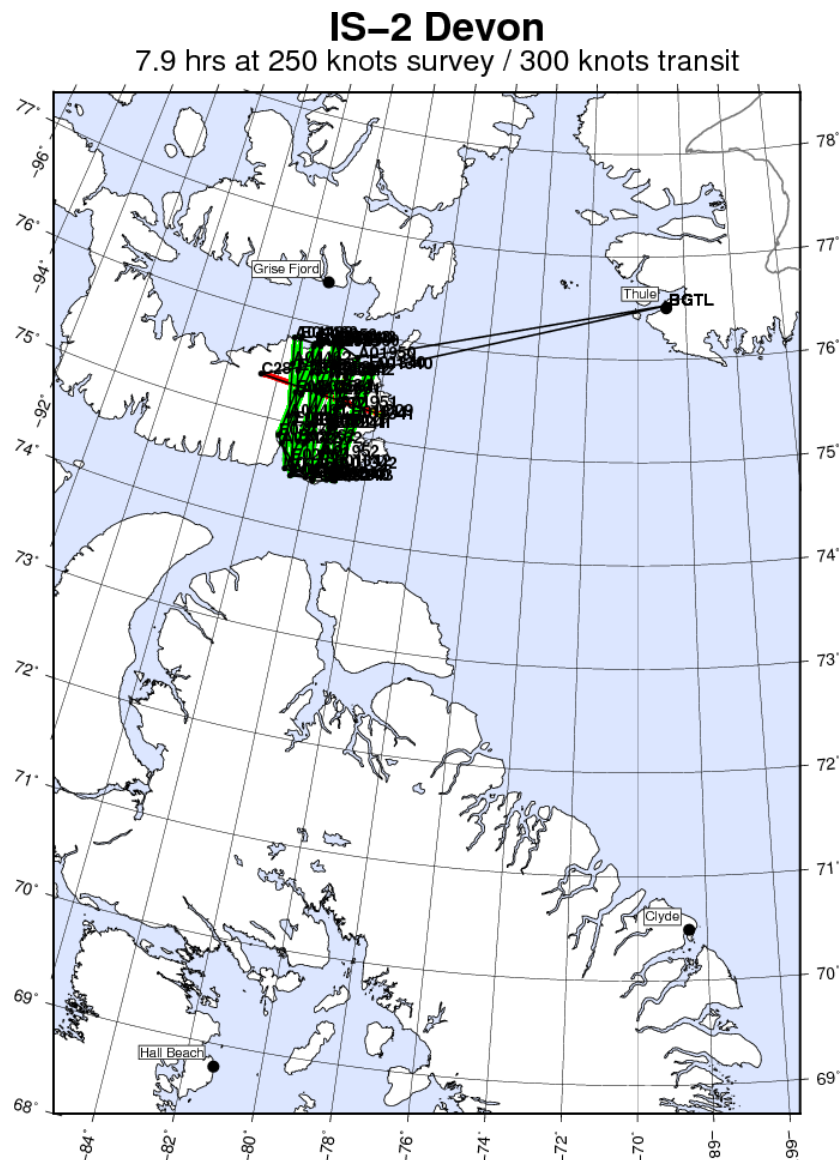
**Flight Priority:** high

**ICESat-2 Tracks:**

A0134,A0195,A0256,E0317,A0446,A0385,A0324,E0324,E0385,E0446,A0317,E0256,E0134

**Last Flown:** historical Devon lines in 2017

**Remaining Design Issues:** none



# Land Ice – ICESat-2 Barnes / Thule

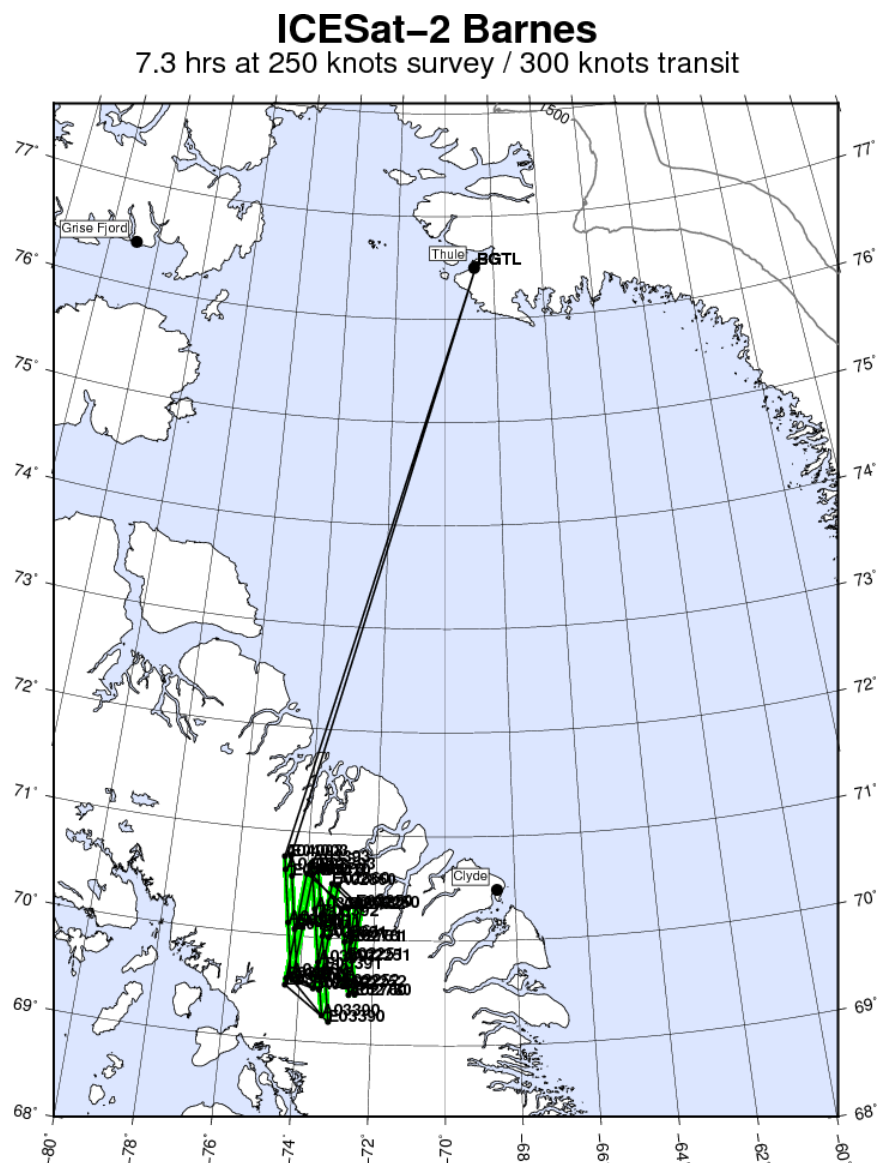
This is a new mission for 2019, designed to sample the left and right beam pairs of ICESat-2 over the Barnes Ice Cap and nearby undulating bare rock (likely to be snow-covered in April). The intention is to validate the geolocation of ICESat-2 footprints. The pattern of ICESat-2 ground tracks is nearly repeated, targeting the left beam pair on one pass and the right beam pair on the other. We validate range biases on the center beam pair during other missions.

**Flight Priority:** high

**ICESat-2 Tracks:** A0400,A0286,A0225,A0278,A0347,A0339,E0339,E0347,E0278,E0225,E0286,E0400

**Last Flown:** new flight

**Remaining Design Issues:** none



# Land Ice – IceSat-2 North / Thule

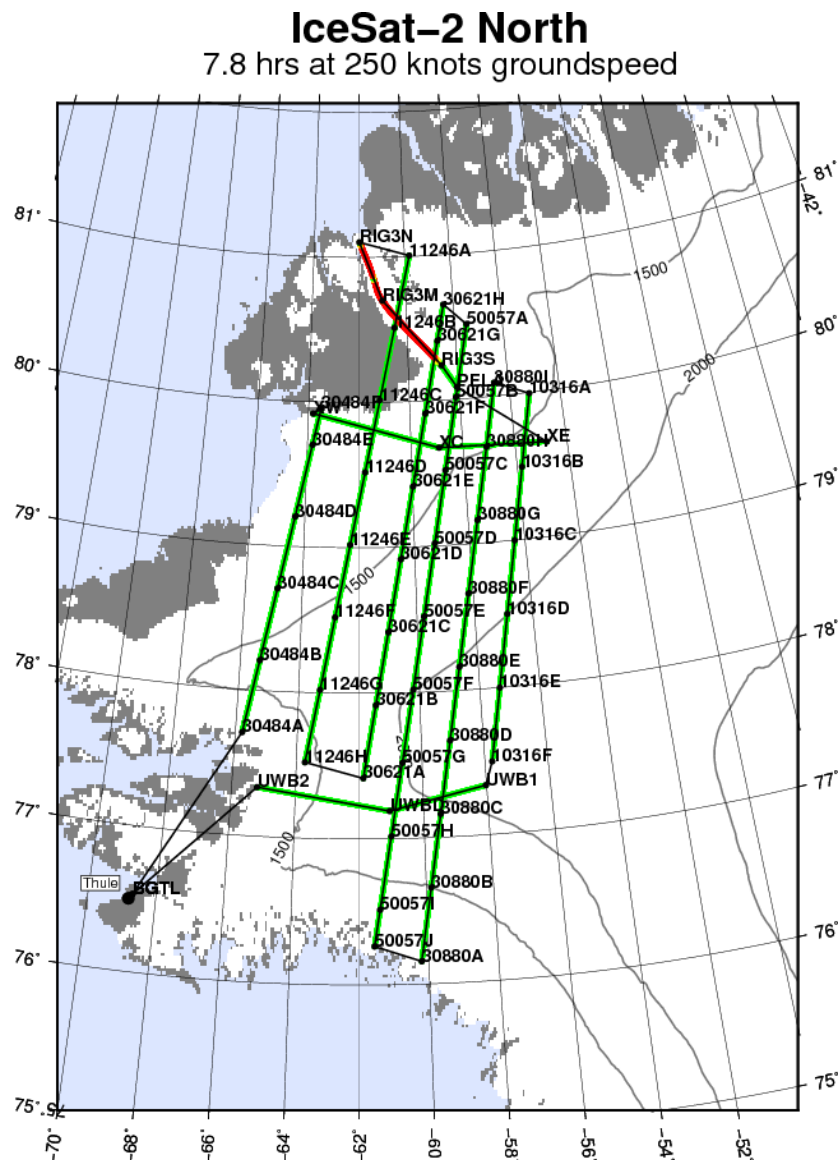
This mission is designed to overfly planned IceSat-2 ground tracks over a wide range of ice regimes near Thule. We center some of the flightlines on each of three beam pairs (left, nadir and right) in turn, sampling at least one of each beam pair during this mission. The east-west crossing line is designed to capture as many ascending/descending crossovers as possible. We also fly a particular flowline of Petermann Glacier which has been sampled intermittently during the ATM and OIB eras, overflying two GCNet sites in the process. For 2018 we modify the return leg to Thule to overfly a segment of an Ultra-wideband radiometer (UWBRAD) flight line, at the request of Ken Jezek.

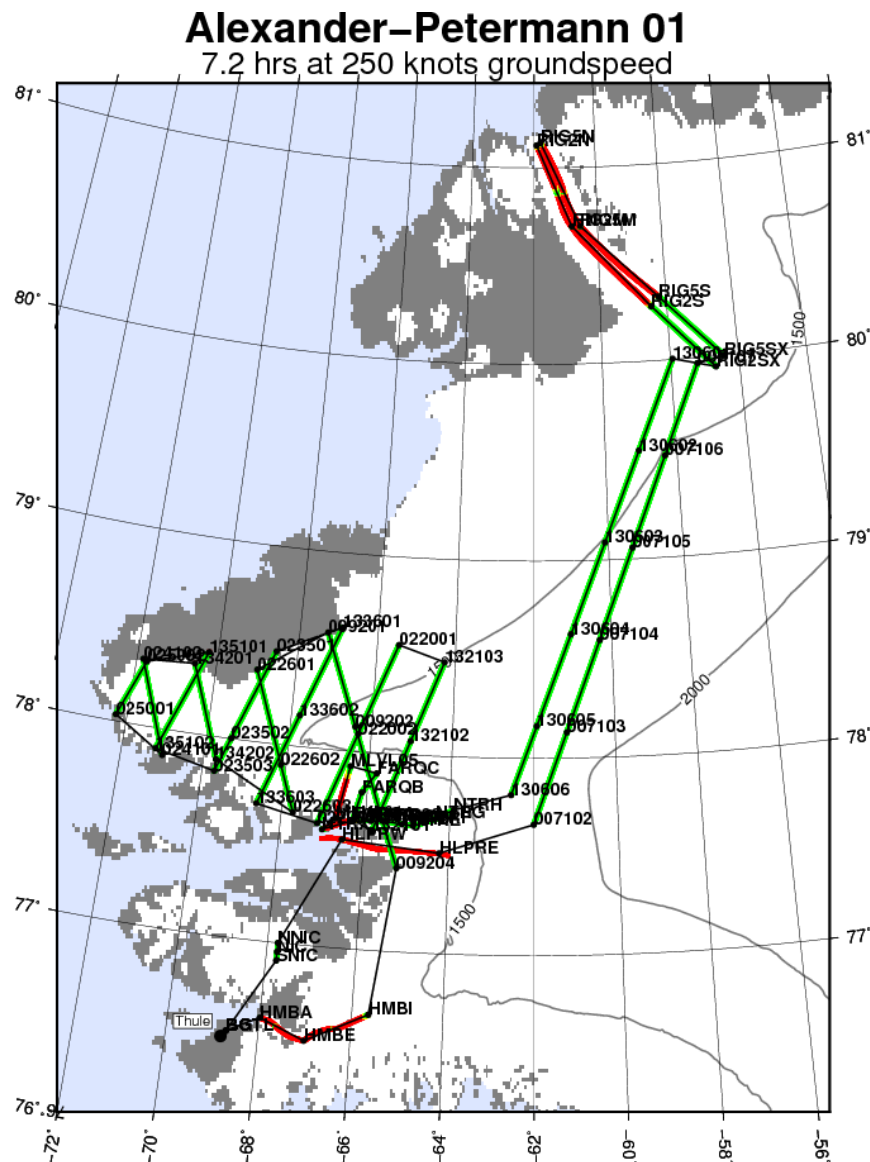
**Flight Priority:** baseline (annual repeat flight)

**IceSat-2 Track:** 0484,1246,0621,0057,0880,0316

**Last Flown:** 2018

**Remaining Design Issues:** none





# Land Ice – Humboldt 01 / Thule

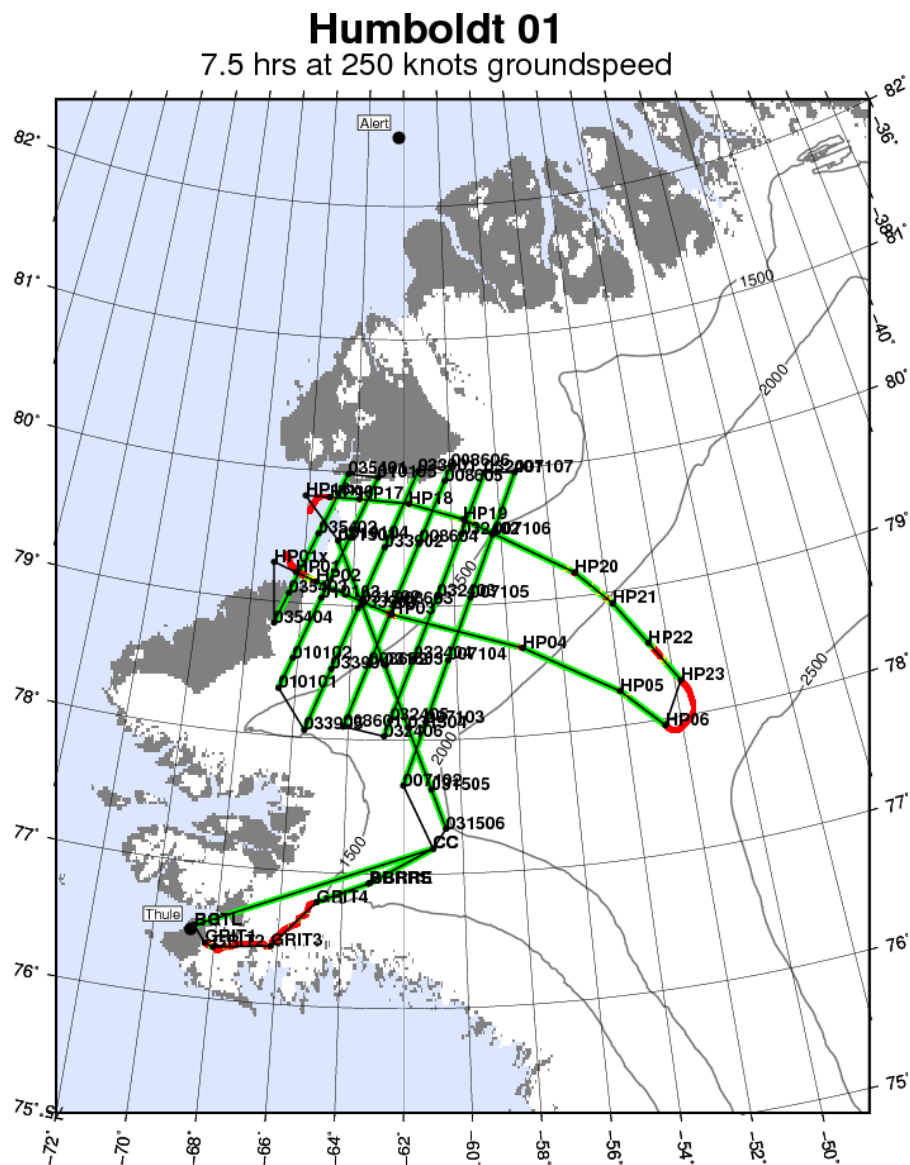
This mission is designed to repeat two historical ATM lines which follow flowlines down the Humboldt Glacier, and several descending ICESat tracks which parallel the terminus. We also fly the GrIT traverse route between Thule and Camp Century, as well as an associated and collocated field site known as “2 Barrels”.

**Flight Priority:** low (multi-year repeat flight)

**ICESat Track:** 0071,0324,0086,0339,0101,0354,0315

## Last Flown: 2017

**Remaining Design Issues:** none



# Land Ice – Humboldt 02 / Thule

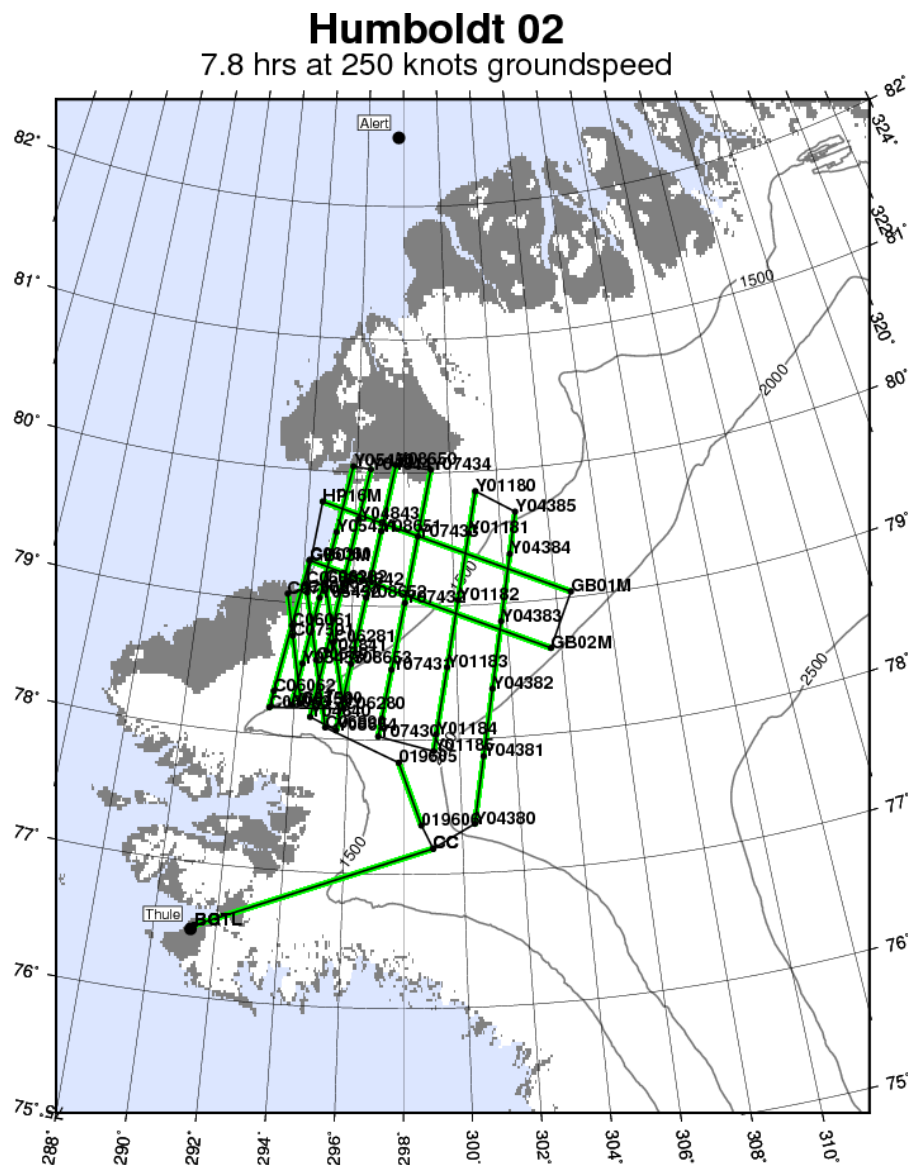
This is a new mission, designed to establish two new along-flow lines and interlace the ICESat lines flown in Humboldt 01 with the similar and interleaving IceSat-2 tracks. All of the IceSat-2 ground tracks are for the center beam pair. For 2019 we shorten the flowlines slightly and add short IceSat-2 tracks off the southern margin of Humboldt, at the suggestion of Alex Gardner.

**Flight Priority:** high

**SatelliteTrack:** 0196 (IS-1), Y0438,Y0118,Y0743,Y0865,Y0484,Y0545,C0750,C0628,C0606 (IS-2)

## Last Flown: new flight

**Remaining Design Issues:** none



# Land Ice – North Bed Gap 01 / Thule

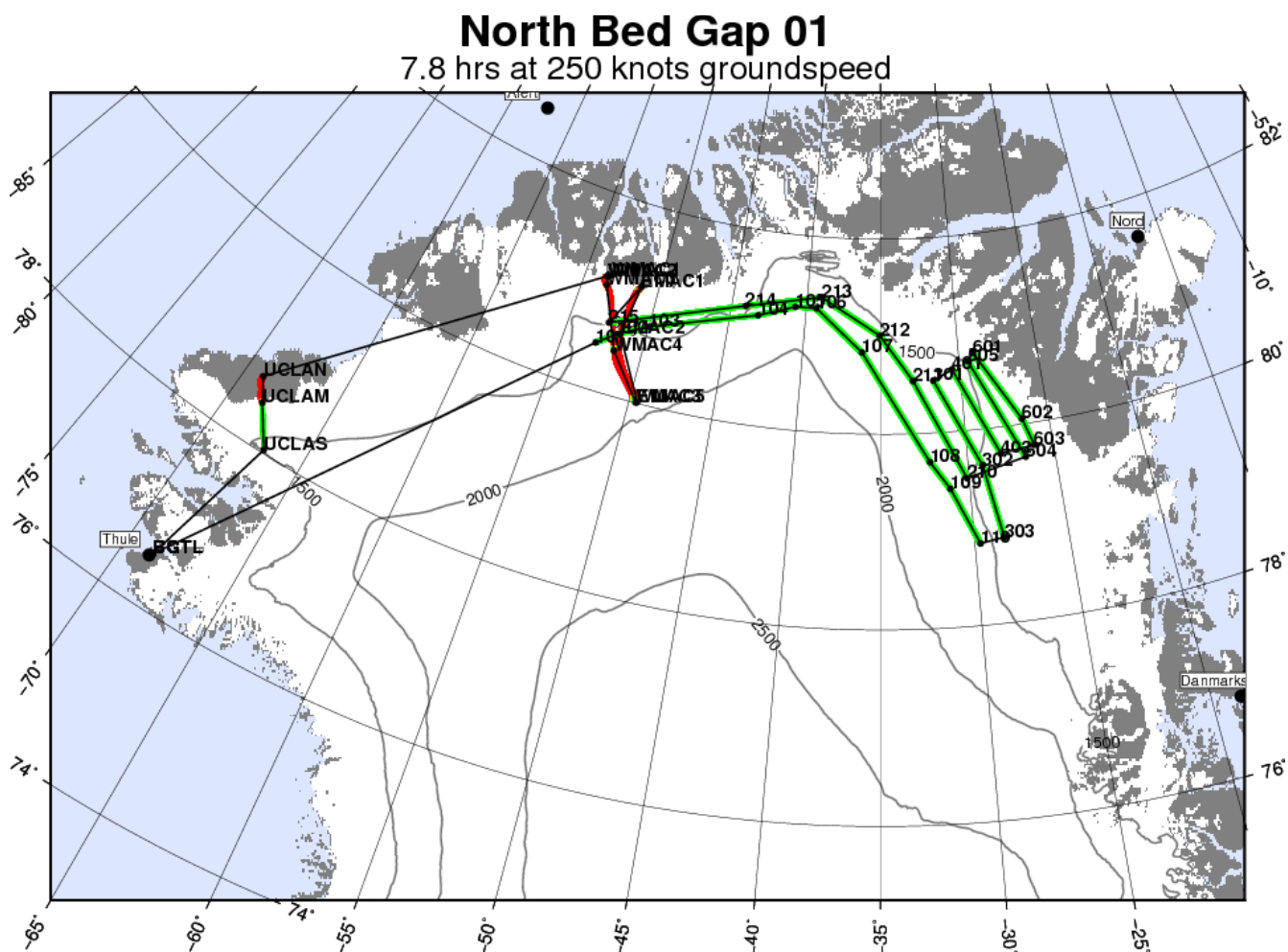
This new mission for 2019 addresses gaps in bed measurements identified by Mathieu Morlighem on the northern and northeastern flank of the ice sheet. We also fly two short flowlines in the vicinity of Steensby and Ryder Glaciers at the request of MacGregor et al, with the purpose of recovering thickness, and possibly layering, in an area with the best surface exposure of pre-Holocene ice in all of Greenland. This data would enable future modeling there to support a possible “horizontal ice core” effort. Finally, we fly a line across the margin of the Hiawatha ice lobe and across a river channel in its proglacial area, at the request of Larry Smith.

**Flight Priority:** high

**ICESat Track:** none

**Last Flown:** new flight

**Remaining Design Issues:** none



# Land Ice – North Glaciers 01 / Thule

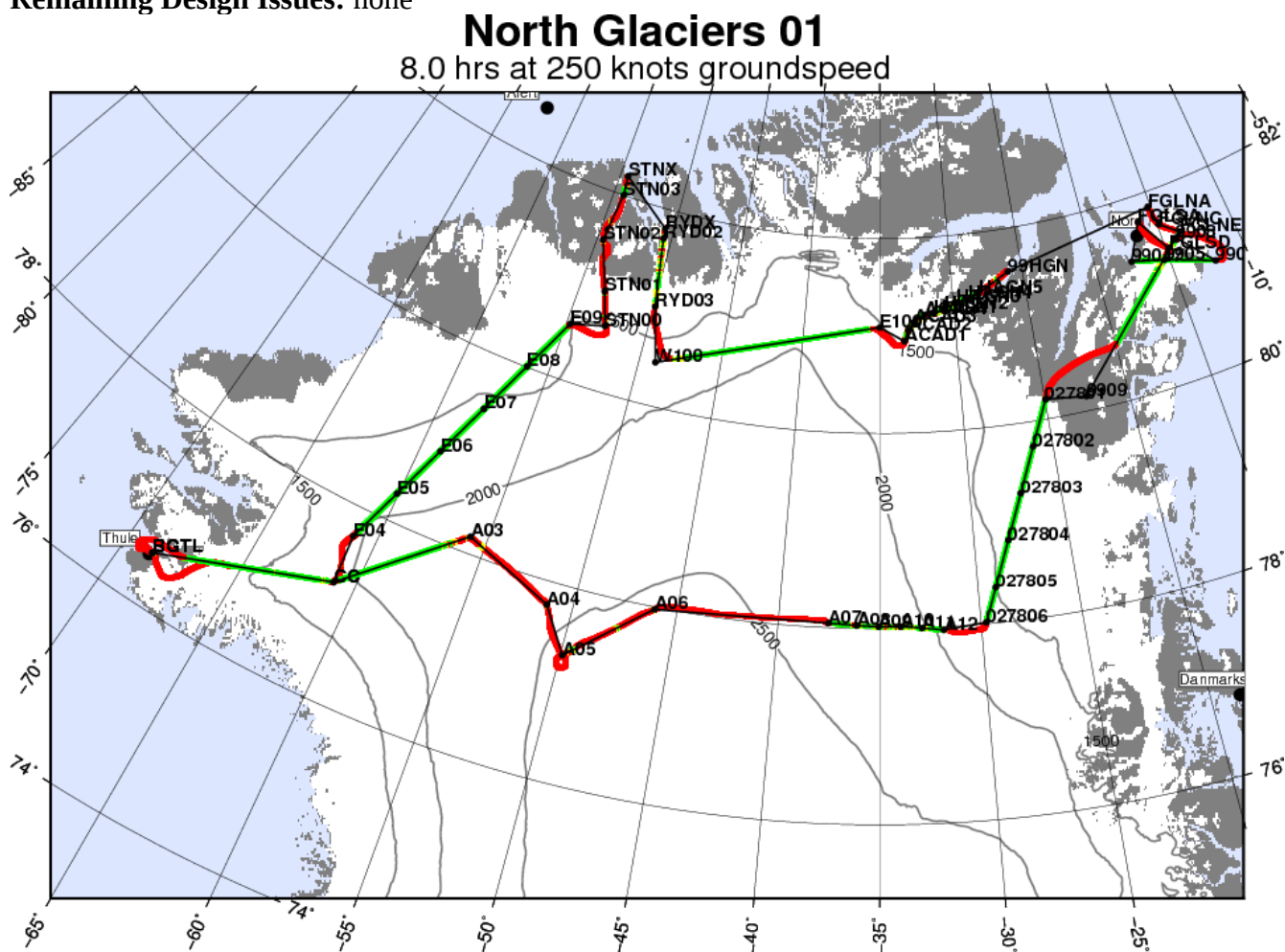
This mission is designed to resurvey historical ATM longitudinal surveys of several glaciers in northern Greenland, including Steensby, Ryder, and Hagen Glaciers. The maneuver connecting lower Steensby and Ryder glaciers has been modified to collect straight-line data over the fjords for better gravity data. It also re-occupies ATM lines on the Flade Ice Cap, near Station Nord, and returns to Thule along the British North Greenland Expedition traverse line, which was also flown by ATM in 2002. We also add two new glacier centerlines for small glaciers draining the Flade Isblink.

**Flight Priority:** medium (multi-year repeat flight)

**ICESat Track:** 0278

**Last Flown:** 2015

**Remaining Design Issues:** none



# Land Ice – North Glaciers 02 Prime / Thule

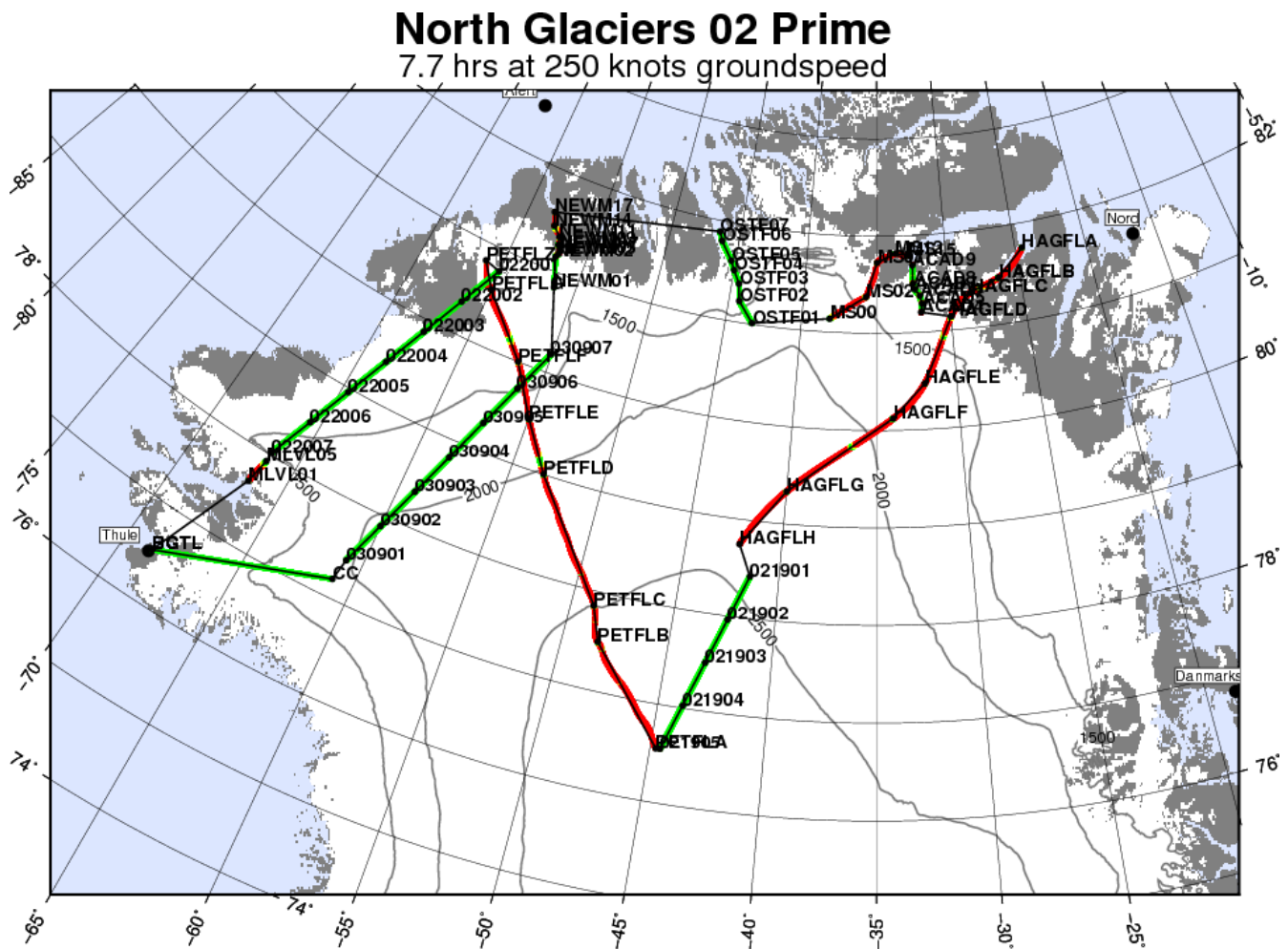
This mission is designed to resurvey a historical ATM longitudinal survey of Academy Glacier, plus several other glaciers. These include Ostfjord, Maria Sophia, and a (possibly unnamed) glacier emptying into Newman Bay. We also survey flowlines of the Hagen and Petermann glaciers all the way from their termini to the ice divide.

**Flight Priority:** low (multi-year repeat flight)

**ICESat Track:** 0220,0309,0219

## Last Flown: 2017

**Remaining Design Issues:** none



## Land Ice – ICESat-2 Peary Land / Thule

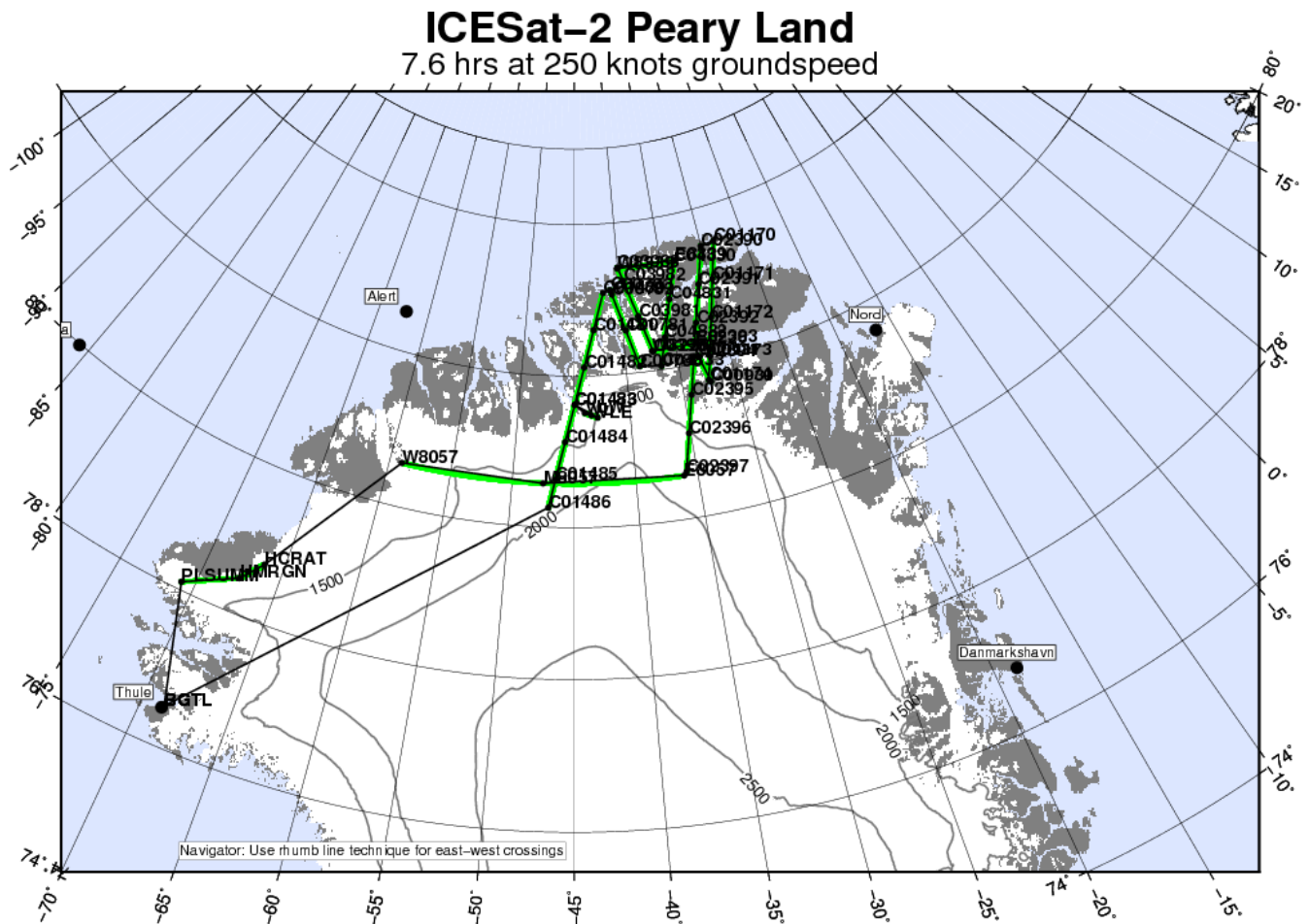
This is a new mission for 2019, designed to sample the strong center beam of ICESat-2 over undulating bare rock (likely to be snow-covered in April) and small ice caps in Peary Land. The intention is to validate the geolocation of ICESat-2 footprints. We also fly along three parallels of low-latency IS-2 crossovers. Finally we overly four sites requested by Jason Briner (Prudhoe Land Summit, Hiawatha Crater, Hiawatha Margin, and Victoria Fjord).

**Flight Priority:** low

**ICESat-2 Tracks:** C0148,C0078,C0483,C0398,C0239,C0117,C0093

## Last Flown: new flight

**Remaining Design Issues:** none



# Land Ice – Zachariae-79N / Thule

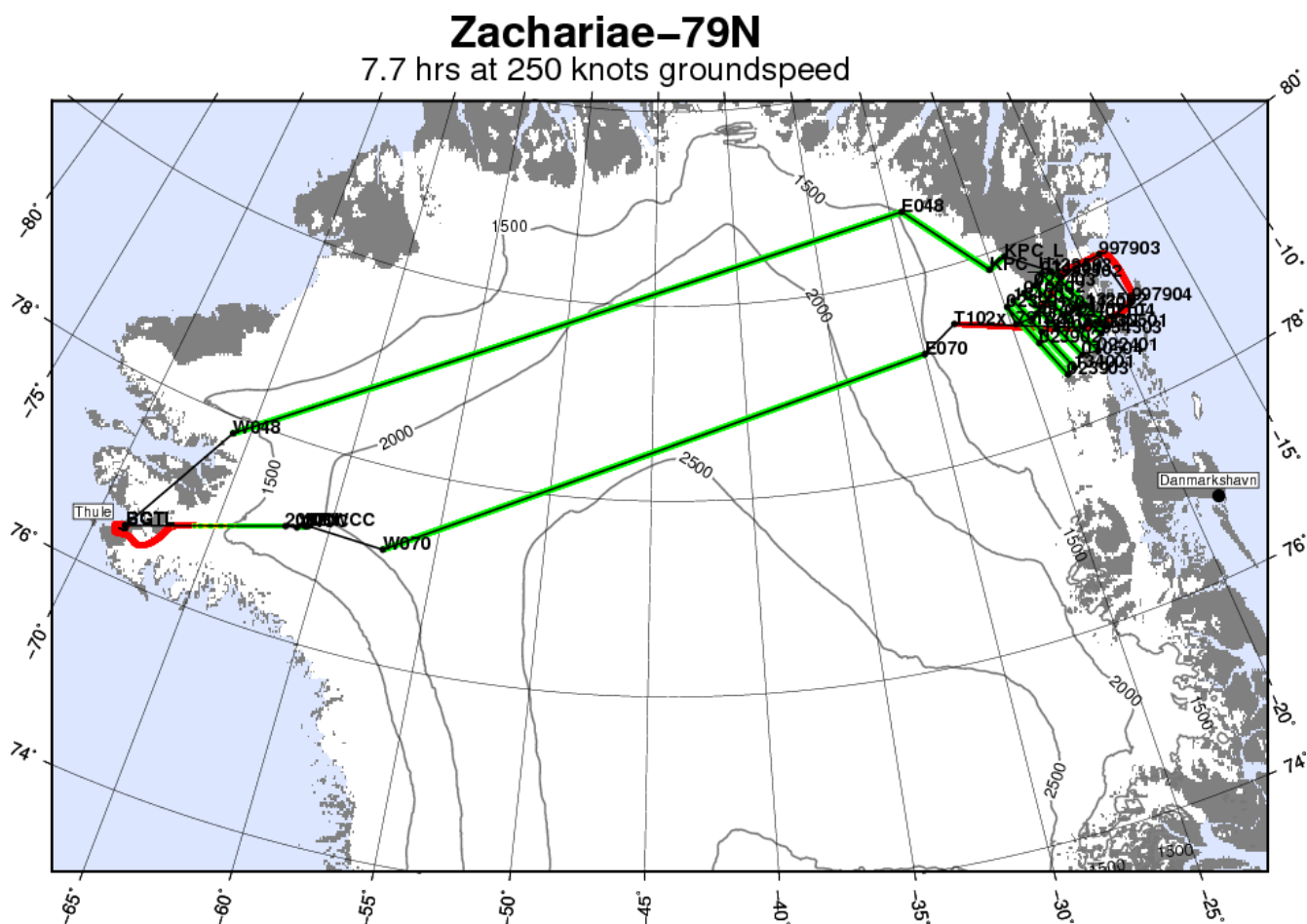
This mission reoccupies the centerlines of the Zachariae and 79N glaciers, plus flies a grid of six ascending IceSat-1 tracks similar to one originally flown by OIB in 2012, but moved upstream by two IceSat-1 groundtracks to account for the breakup of the lower ice shelf. It also overflies a pair of PROMICE sites immediately north of 79N Glacier. We transit to the northeast region along a historical ATM line dating back to 1994. For 2019 we replace the east-west transit lines with new master grid lines, selected to fill gaps in knowledge of bedrock.

**Flight Priority:** baseline (annual repeat flight)

**ICESat Track:** 0105,0224,0239,0343,1325,1340

**Last Flown:** 2018

**Remaining Design Issues:** none



# Land Ice – Northeast Glaciers 02 / Thule

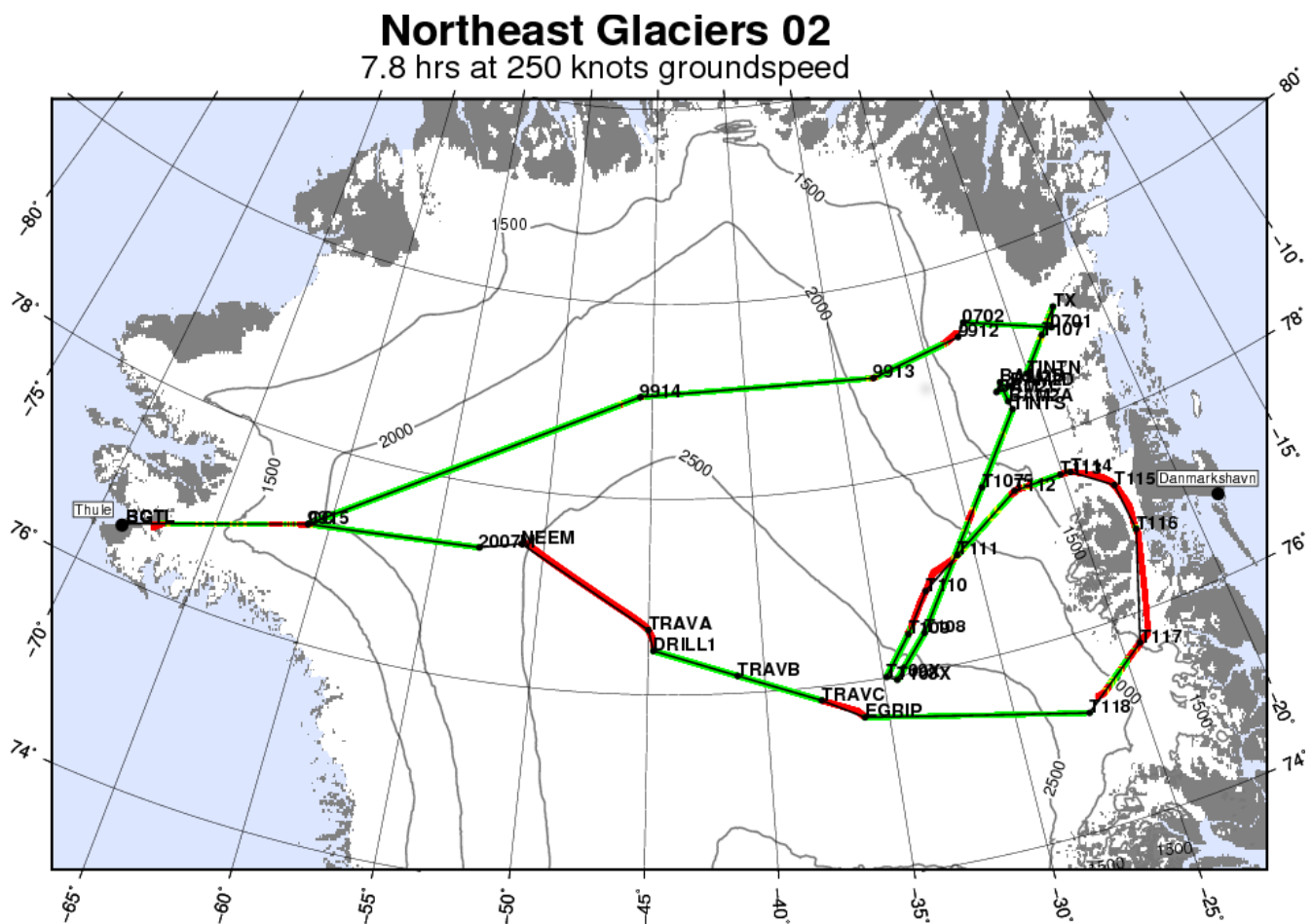
This mission reoccupies the centerlines of the Storstrommen and L Bistrup glaciers, as well as an extension of the Northeast Greenland Ice Stream from Zachariae and 79N Glaciers into the main ice sheet. This southward extension along the ice stream reflies the 2 May 2007 lines, and extends them 60 km farther up the trunk of the ice stream. We transit to and from the northeast region along a historical ATM line dating back to 1994, and along a Danish ground traverse route connecting NEEM and EGRIP core sites. Measurements collected during the ground traverse may permit enhanced interpretation of shallow radar data from OIB. For 2018, we conduct crossing passes over a subglacial site of interest, at the request of Jon Bamber.

**Flight Priority:** medium (multi-year repeat flight)

**ICESat Track:** none

**Last Flown:** portions in 2014

**Remaining Design Issues:** none



# Land Ice – North Central Gap 01 IS-2 / Thule

This mission, along with the North Central Gap 02 and 03 missions, are primarily designed to fill a gap in altimetry and radar coverage of the north-central portion of the ice sheet. The flight was modified for 2015, where we removed the centerlines of Zachariae and Storstrommen Glaciers (covered in other flights), and added reflights of four 2010 grid lines on the upper Zachariae/79N catchment, extended upstream centerlines of both glaciers, and a flowline passing through the TUNU core site. For 2019 we modify the east-west crossings to target low-latency IS-2 crossover latitudes, we replace the 2010 grid lines with low-latency ICESat-2 ground tracks, and we also fly parallel extensions of previous lines on the upper NEGIS. These extension lines are new.

**Flight Priority:** high (multi-year repeat flight)

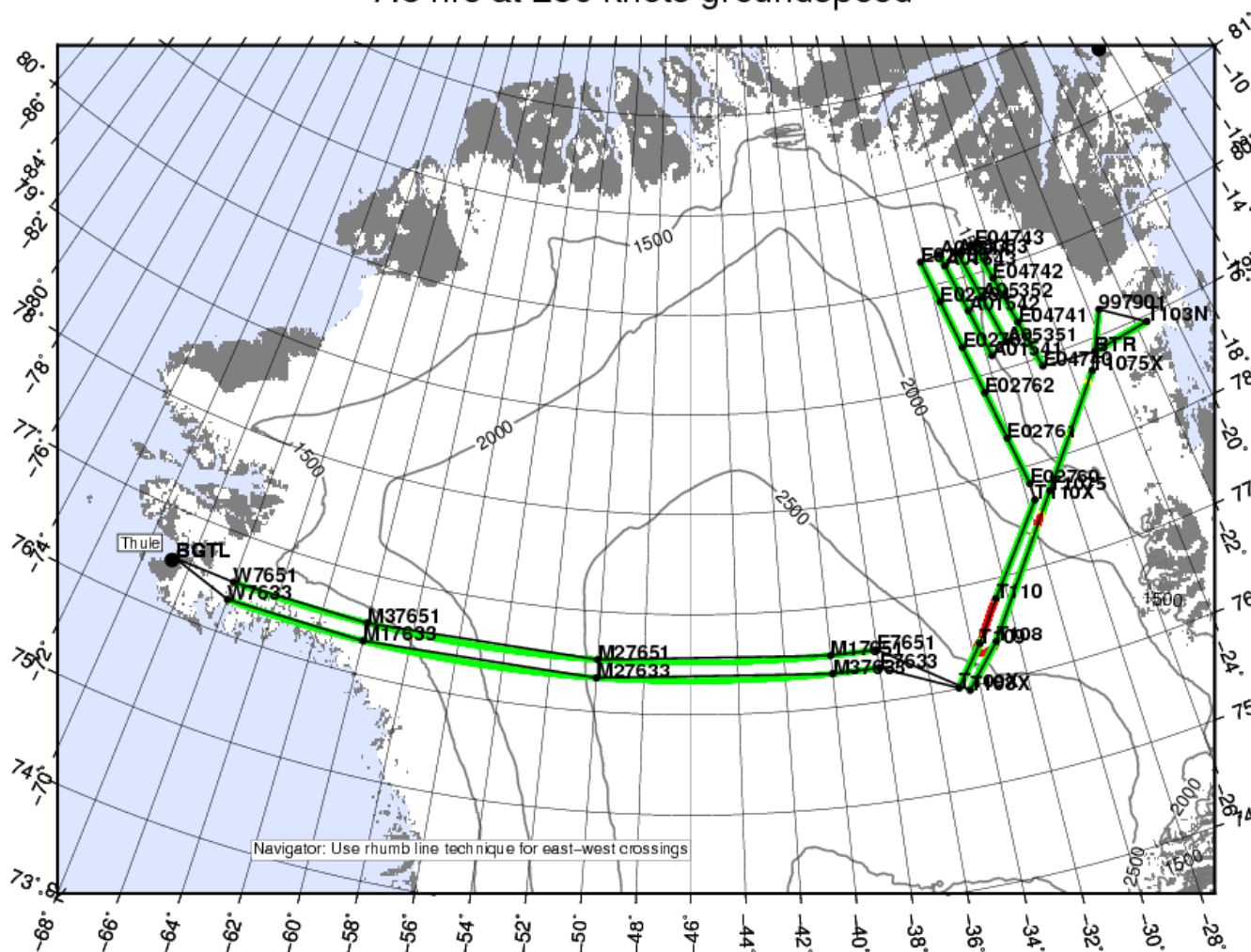
**ICESat-2 Tracks:** E0276,A0154,A0535,E0474

## Last Flown: 2017

**Remaining Design Issues:** none

## North-Central Gap 01 IS-2

7.8 hrs at 250 knots groundspeed



# Land Ice – North Central Gap 02 / Thule

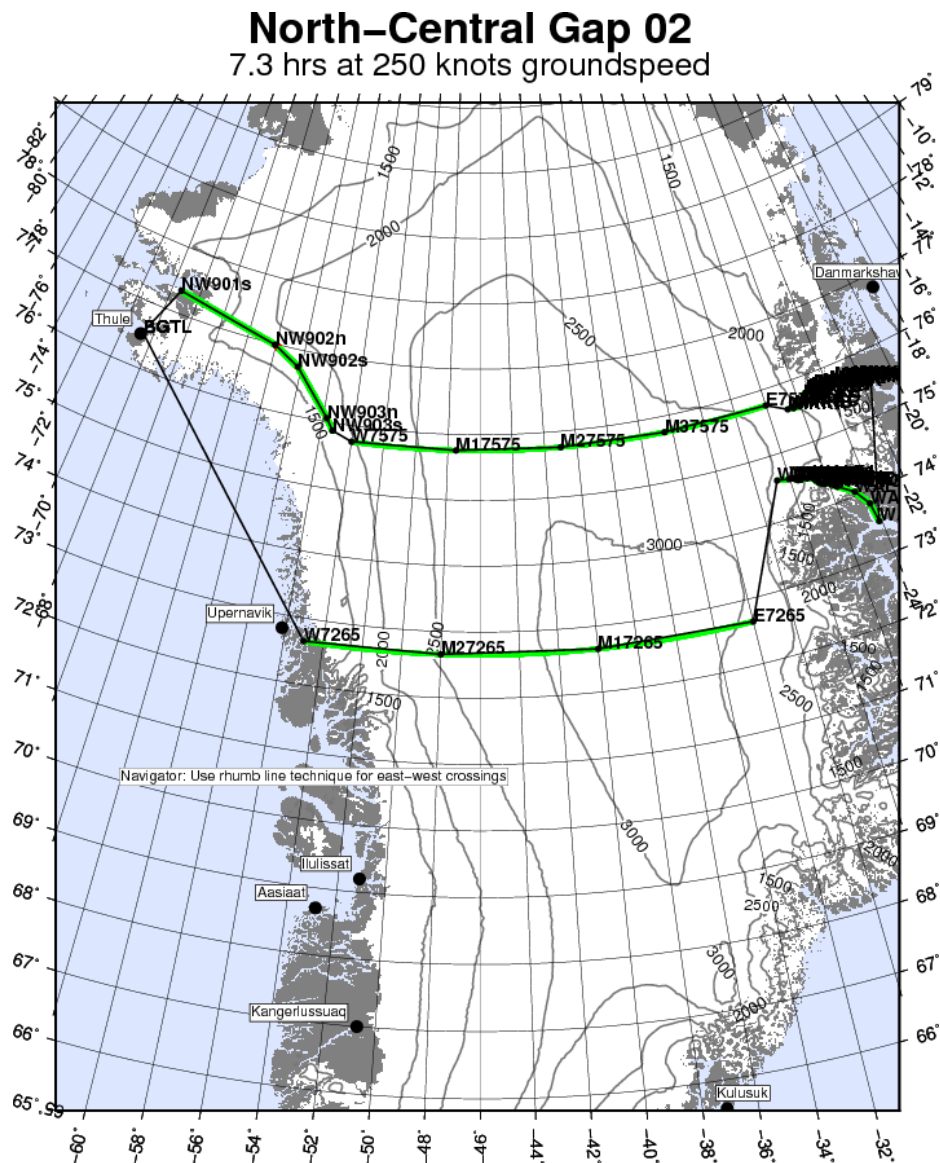
This mission, along with the North Central Gap 01 and 03 missions, are primarily designed to fill a gap in altimetry and radar coverage of the north-central portion of the ice sheet. In this flight, we establish new centerlines of the Mikkelsen and Waltershausen glaciers, and we refly portions of the northwest coast-parallel grid flown from 2010-2012. For 2019 we modify the east-west crossings to target low-latency IS-2 crossover latitudes.

**Flight Priority:** medium (multi-year repeat flight)

**ICESat Track:** none

**Last Flown:** 2015

**Remaining Design Issues:** none



# Land Ice – North Central Gap 03 / Thule

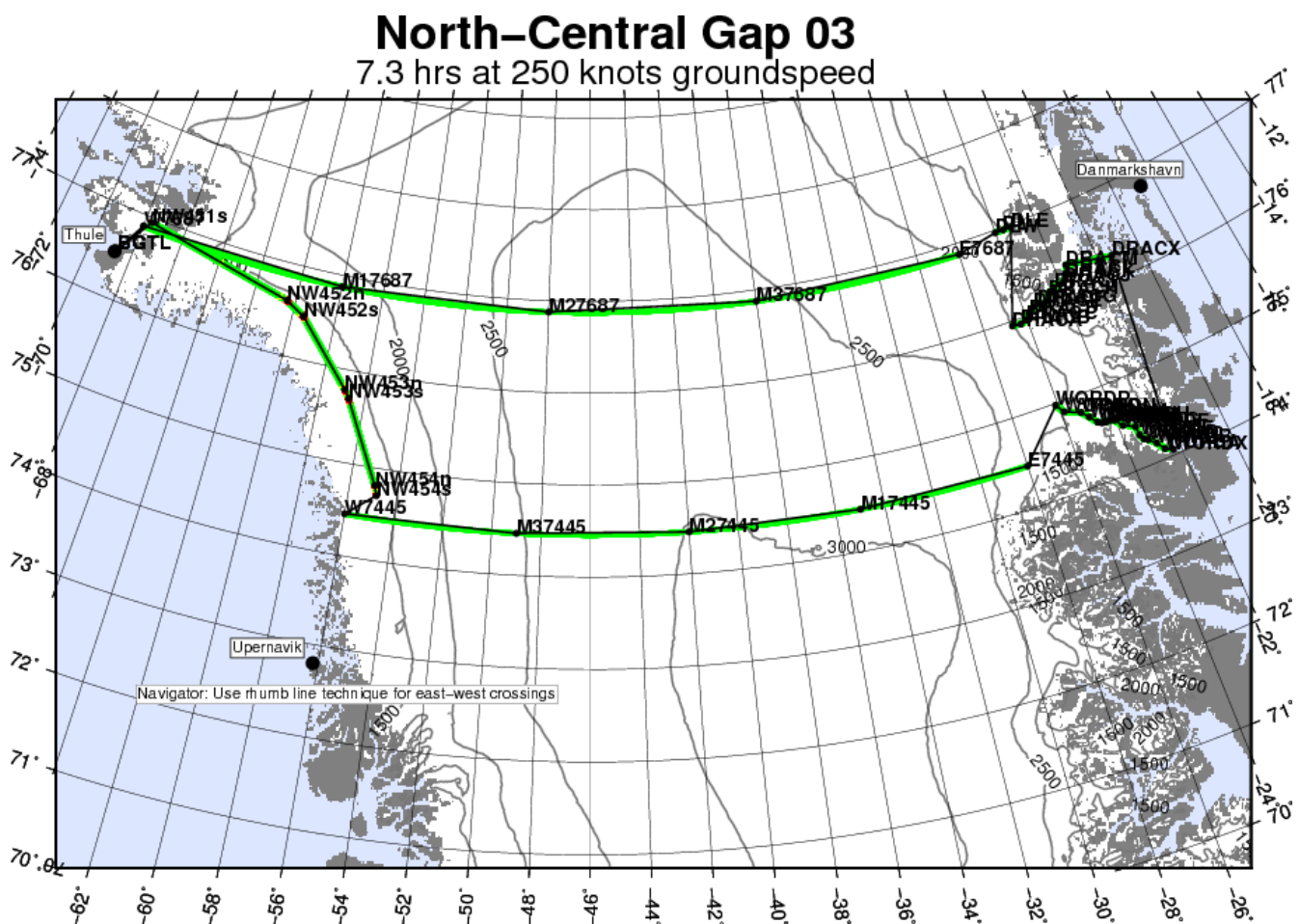
This mission, along with the North Central Gap 02 and 03 missions, are primarily designed to fill a gap in altimetry and radar coverage of the north-central portion of the ice sheet. In this flight, we also re-fly centerlines of the Drachmann and Wordie glaciers, and portions of the northwest coast-parallel grid flown from 2010-2012. For 2019 we modify the east-west crossings to target low-latency IS-2 crossover latitudes, and we add a flyover of a site in Dronning Louise Land at the request of Jason Briner.

**Flight Priority:** low (multi-year repeat flight)

**ICESat Track:** none

## Last Flown: 2017

**Remaining Design Issues:** none



# Land Ice – Northeast Grid 05 Prime / Thule

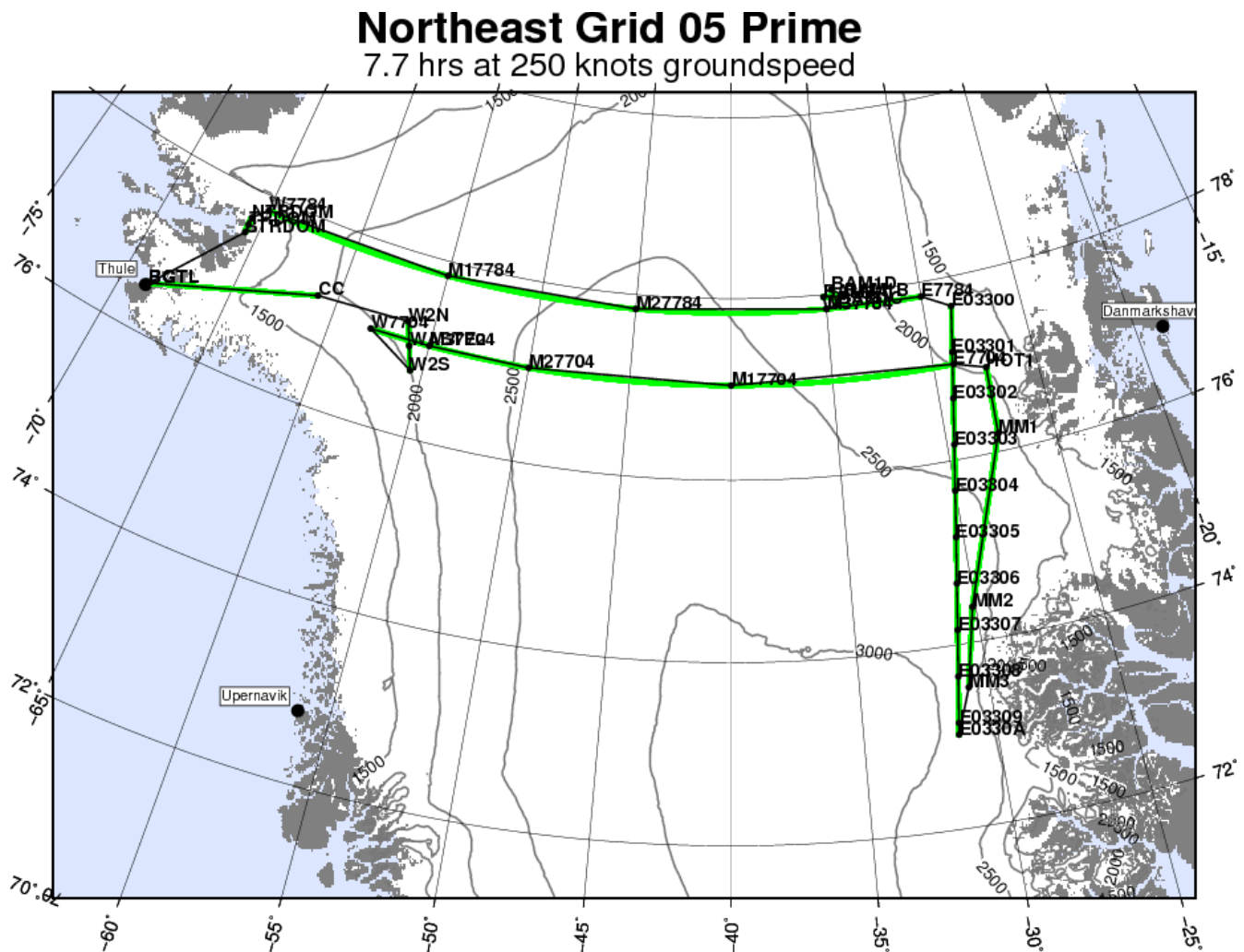
This is a new mission, one of a suite of six flights intended to thoroughly sample the bedrock topography of northeast Greenland along a series of nearly coast-parallel ICESat lines. For 2019 we completely redesign this flight, although the original purpose remains the same. We change the east-west transit lines to follow the latitudes of low-latency ICESat-2 crossovers, and we fly a low-latency IS-2 ground track in the east, which also covers a “hot-spot” in the bed uncertainty. We fly a second roughly north-south line in the east targeted at multiple such hot-spots. We also add brief flyovers of a Bamber-suggested subglacial site in the northeast, a Cold War-era waste site in the west, and a small ice dome between Tracy and Heilprin Glaciers.

**Flight Priority:** high

**ICESat-2 Track:** E0330

**Last Flown:** new flight

**Remaining Design Issues:** none



# Land Ice – West-Central Bed Gap IS-2 / Thule

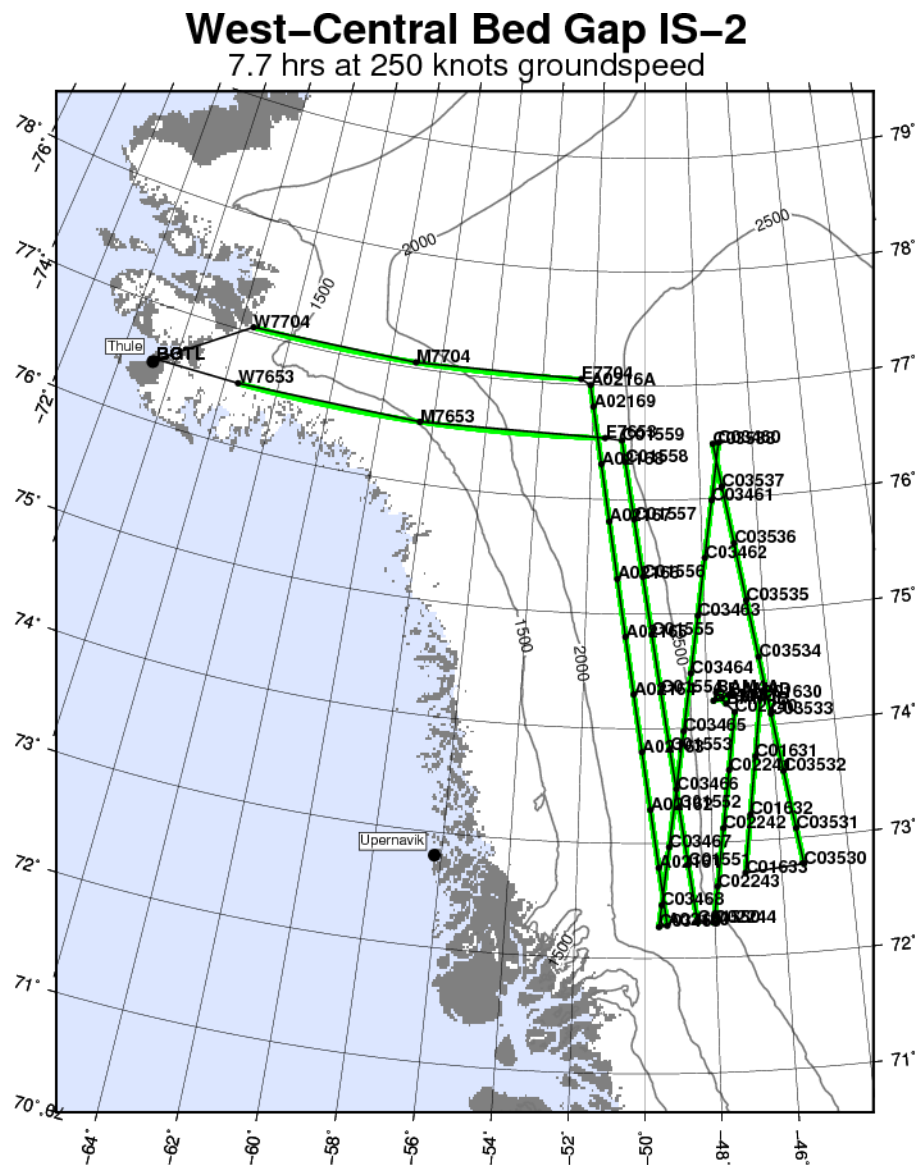
This mission (along with the Kangerlussuaq-based East-Central Bed Gap 01 flight) is designed to address the largest gaps in knowledge of the bedrock geometry still existing in Greenland. It does so along low-latency ICESat-2 ground tracks. We also conduct crossing passes over a subglacial site of interest, at the request of Jon Bamber.

**Flight Priority:** high

**ICESat-2 Tracks:** A0216,C0346,C0353,C0163,C0224,C0155

**Last Flown:** new mission

**Remaining Design Issues:** none



# Land Ice – Northwest Crossover IS-2 / Thule

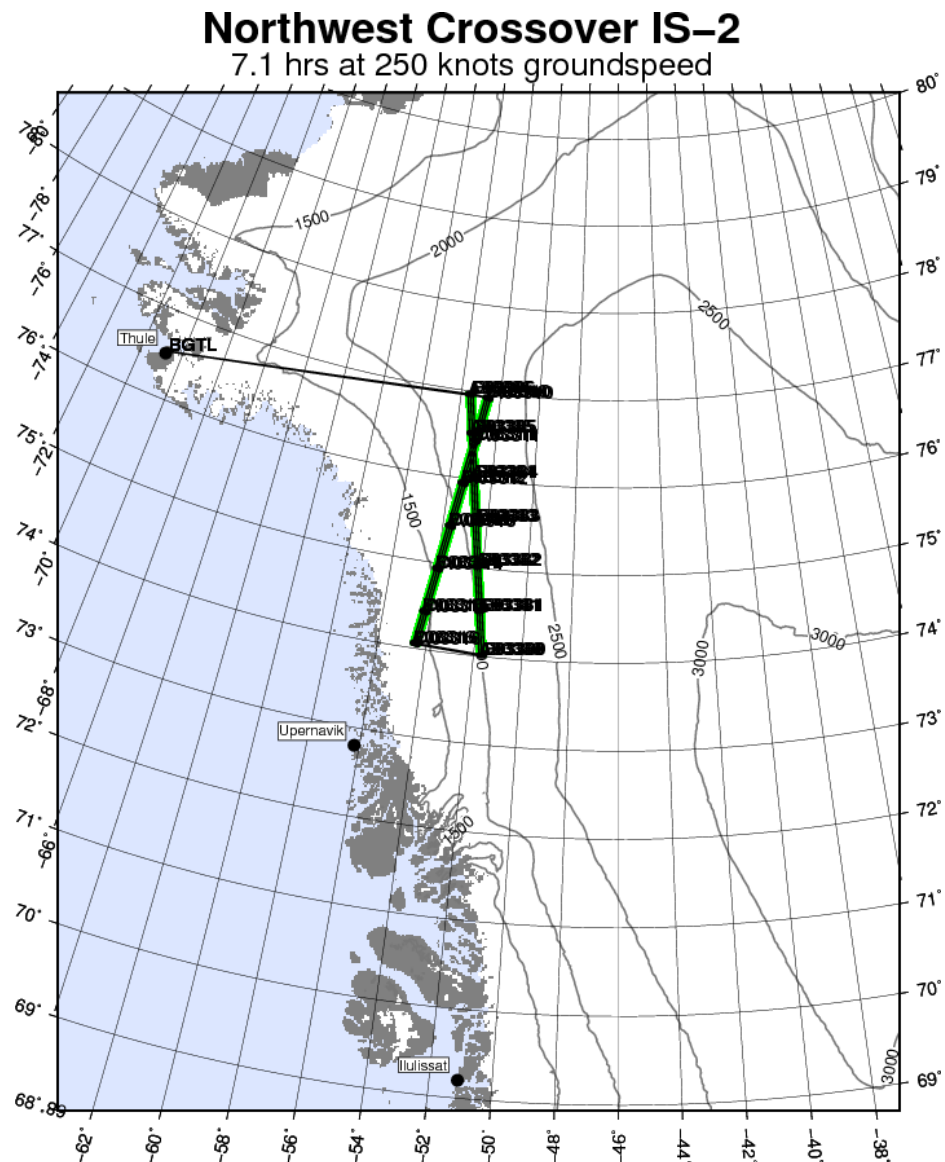
This is a new mission for 2019. It is designed to target a low-latency crossing of ascending and descending ICESat-2 ground tracks along the northwest margin of the Greenland ice sheet. We fly the strong beams of all three beam pairs for both tracks.

**Flight Priority:** medium

**ICESat-2 Tracks:** A0331, C0331, E0331, A0338, C0338, E0338

**Last Flown:** new flight

**Remaining Design Issues:** none



# Land Ice – Northwest Coastal IS-2 / Thule

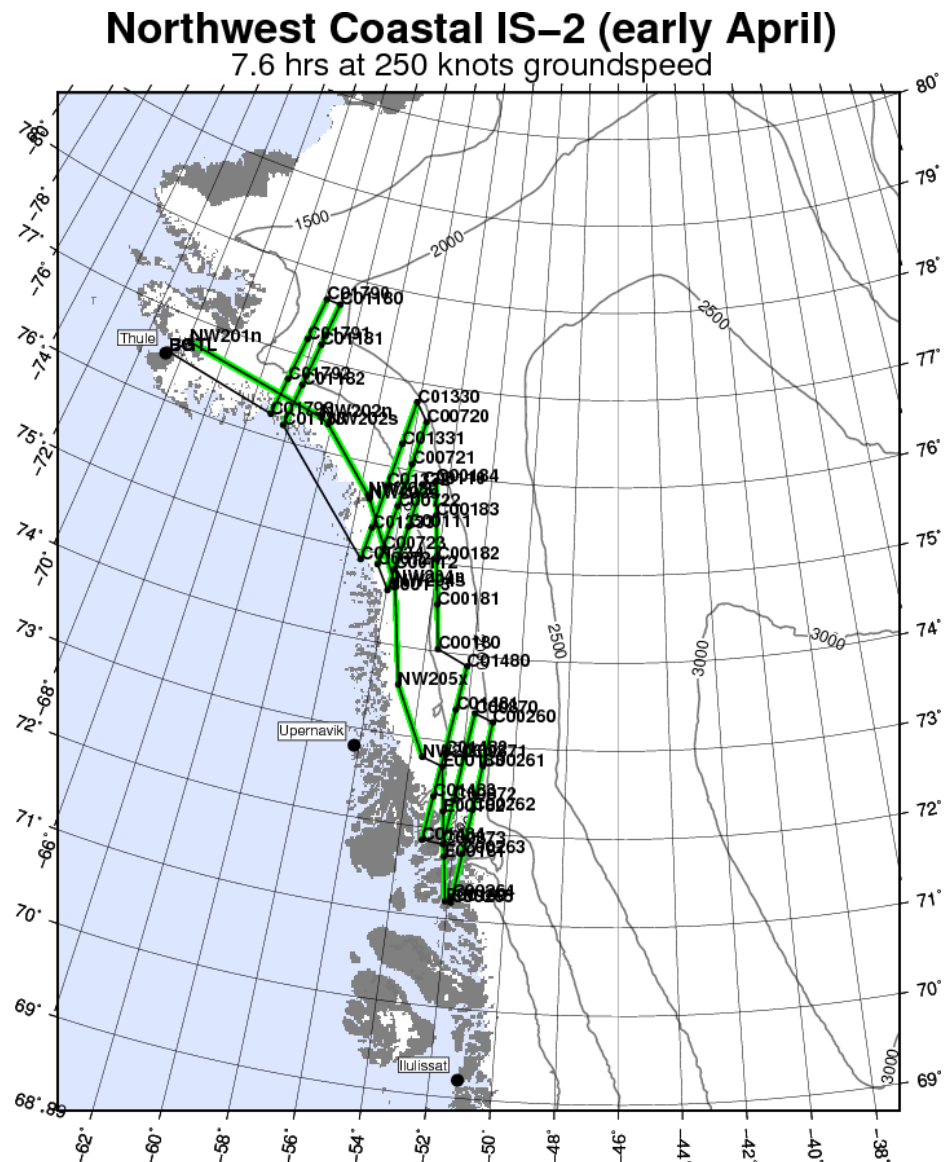
This is a new mission for 2019. It is designed to target a low-latency ICESat-2 ground tracks along the upper Baffin Bay coast, assuming this mission were to be flown in April 2019. We have two versions of this mission, one to be flown in early April and the other to be flown in late April.

**Flight Priority:** high

**ICESat-2 Tracks:** E0018,C0026,C0087,C0148,C0018,C0011,C0072,C0133,C0118,C0179

## Last Flown: new flight

**Remaining Design Issues:** none



# Land Ice – Northwest Glaciers 01 / Thule

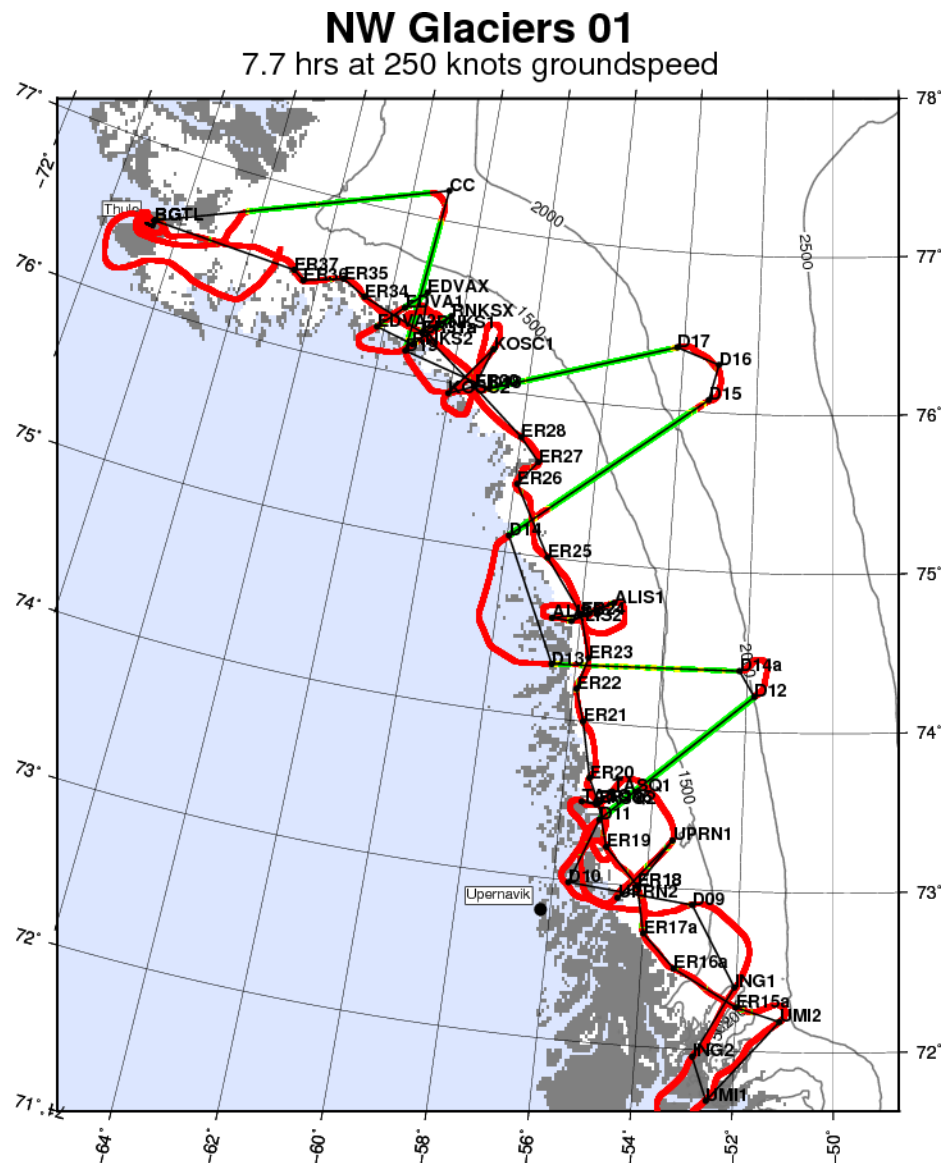
This mission is a repeat of a 2009, 2010, 2011, 2012 and 2014 IceBridge mission. It focuses on the upper Baffin Bay coast, with targeted longitudinal surveys of 12 glaciers in the region and repeats of long-established ATM dh/dt lines which were not targeted at outlet glaciers, but instead were intended to track inland spread of coastal thinning. This had been a baseline OIB flight, but was demoted in 2016 because of its unsuitability to be flown from high altitude during the melt season campaigns.

**Flight Priority:** medium (multi-year repeat mission)

**ICESat Track:** none

**Last Flown:** 2015

**Remaining Design Issues:** none



# Land Ice – Northwest Glaciers 02 / Thule

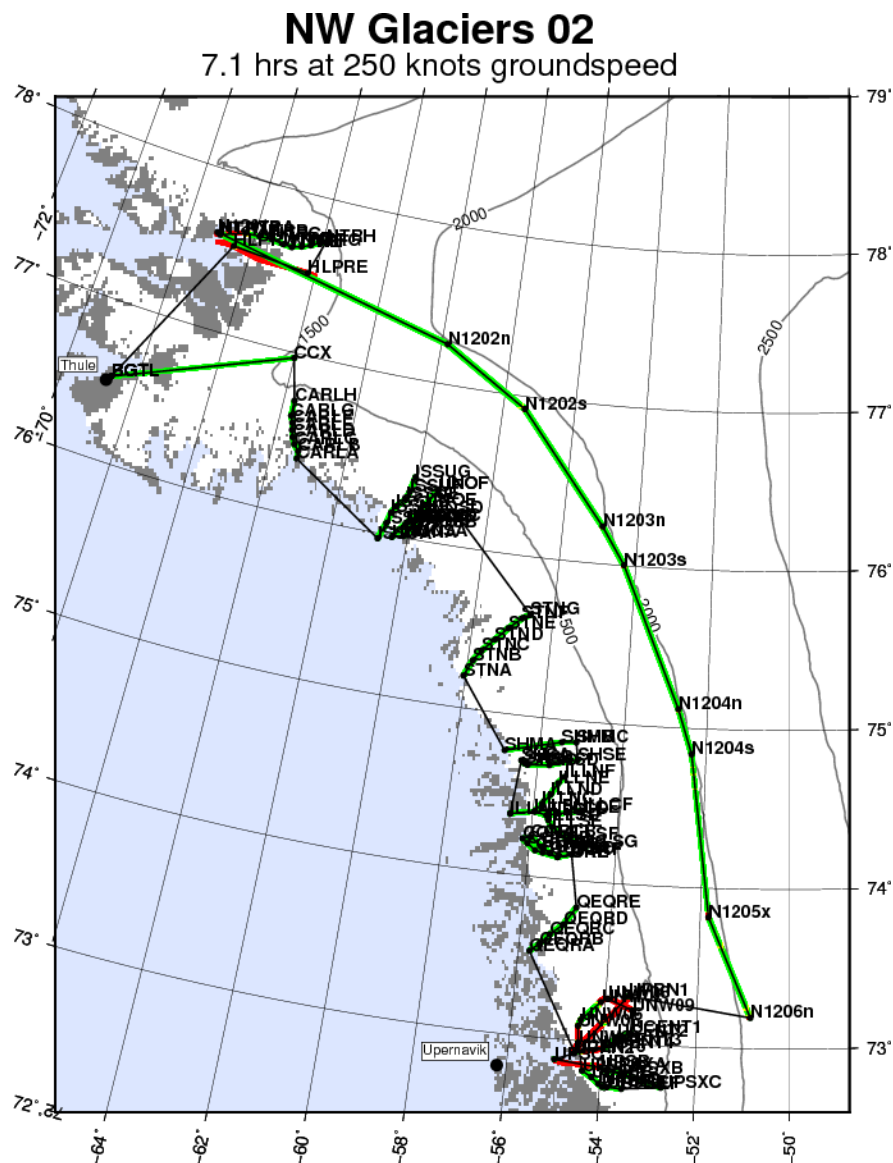
This mission focuses on the upper Baffin Bay coast, with targeted longitudinal surveys of the most significant glaciers in the region not flown prior to this flight's first implementation in 2014. We also resurvey the centerlines of the Tracy and Heilprin glaciers, and we re-fly a previously-flown inland line from the “northwest coastal” suite of missions.

**Flight Priority:** medium (multi-year repeat mission)

**ICESat Track:** none

**Last Flown:** 2014

**Remaining Design Issues:** none



# Land Ice – Northwest Coastal A / Thule

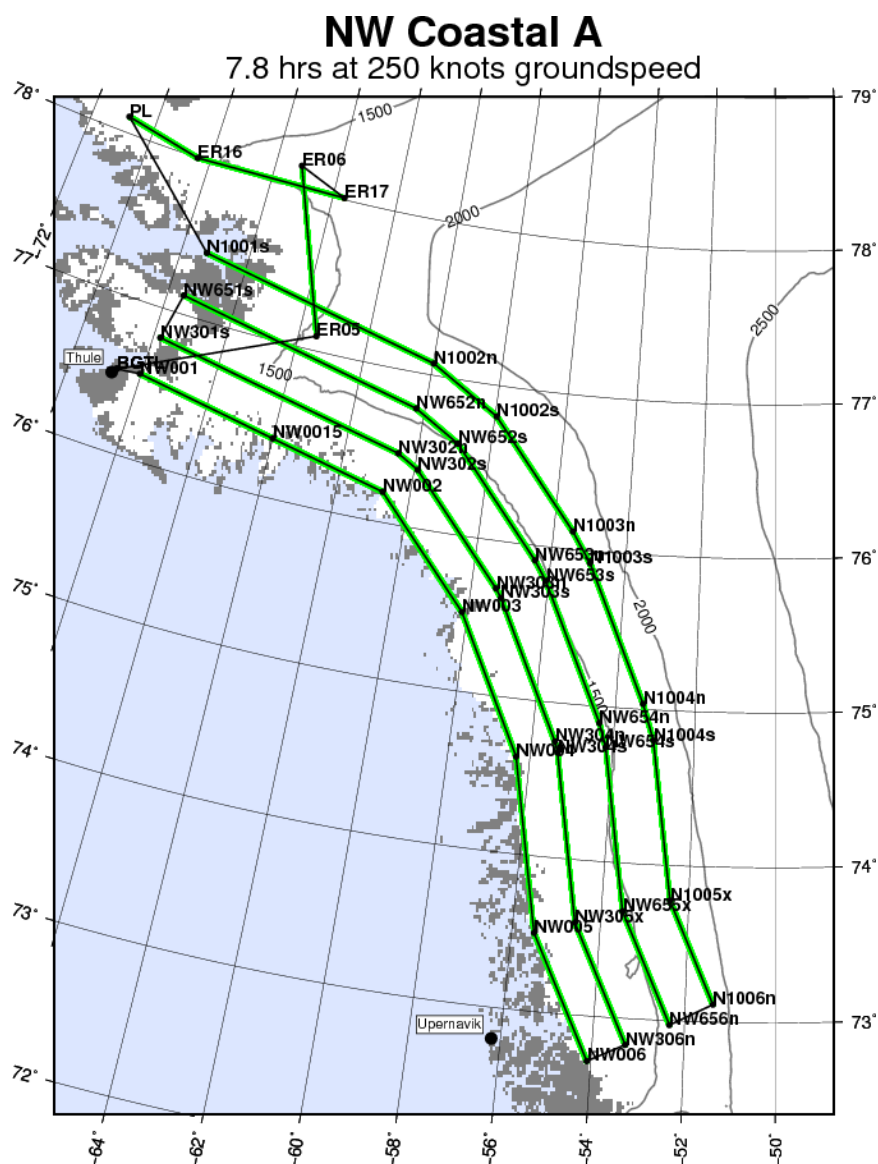
This is a new mission, created from the 2010-2012 “Northwest Coastal” suite of missions by sampling individual coast-parallel lines from those flights to form a grid spaced at 30-35 km from the coast to near the 2000m contour line. This is one of three missions designed in this way, which together form a 10 km grid in the area. The others are Northwest Coastal B and C. We also add two additional bedrock-mapping lines in the Tracy/Heilprin catchment. This flight was assigned a baseline priority for 2016 because it continues an intra-annual time series with the spring and fall 2015 campaigns along these lines. We also overfly a site in Prudhoe Land at the request of Jason Briner.

**Flight Priority:** high (annual repeat flight prior to 2019)

**ICESat Track:** none

**Last Flown:** 2018

**Remaining Design Issues:** none



# Land Ice – ICESat-2 Penny / Kangerlussuaq

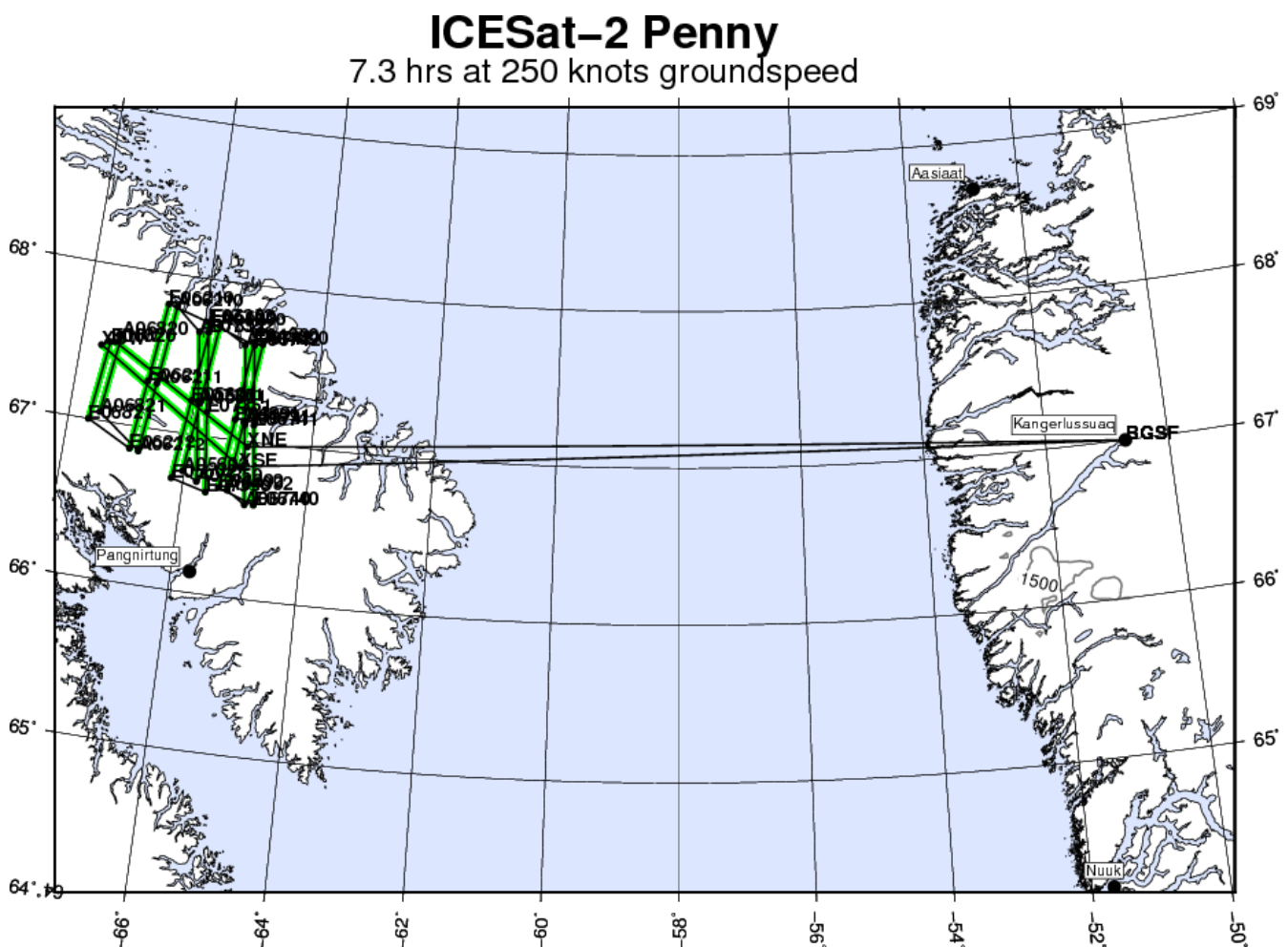
This is a new mission for 2019, designed to sample the left and right beam pairs of ICESat-2 over the Penny Ice Cap and nearby undulating bare rock. The intention is to validate the geolocation of ICESat-2 footprints. The pattern of ICESat-2 ground tracks is nearly repeated, targeting the left beam pair on one pass and the right beam pair on the other. We validate range biases on the center beam pair during other missions.

**Flight Priority:** medium

**ICESat-2 Tracks:** A0682,E0682,A0621,E0621,A0735,E0735,A0560,E0560,A0674,E0674,A0499,E0499

**Last Flown:** new flight

**Remaining Design Issues:** none



# Land Ice – Penny 01 / Kangerlussuaq

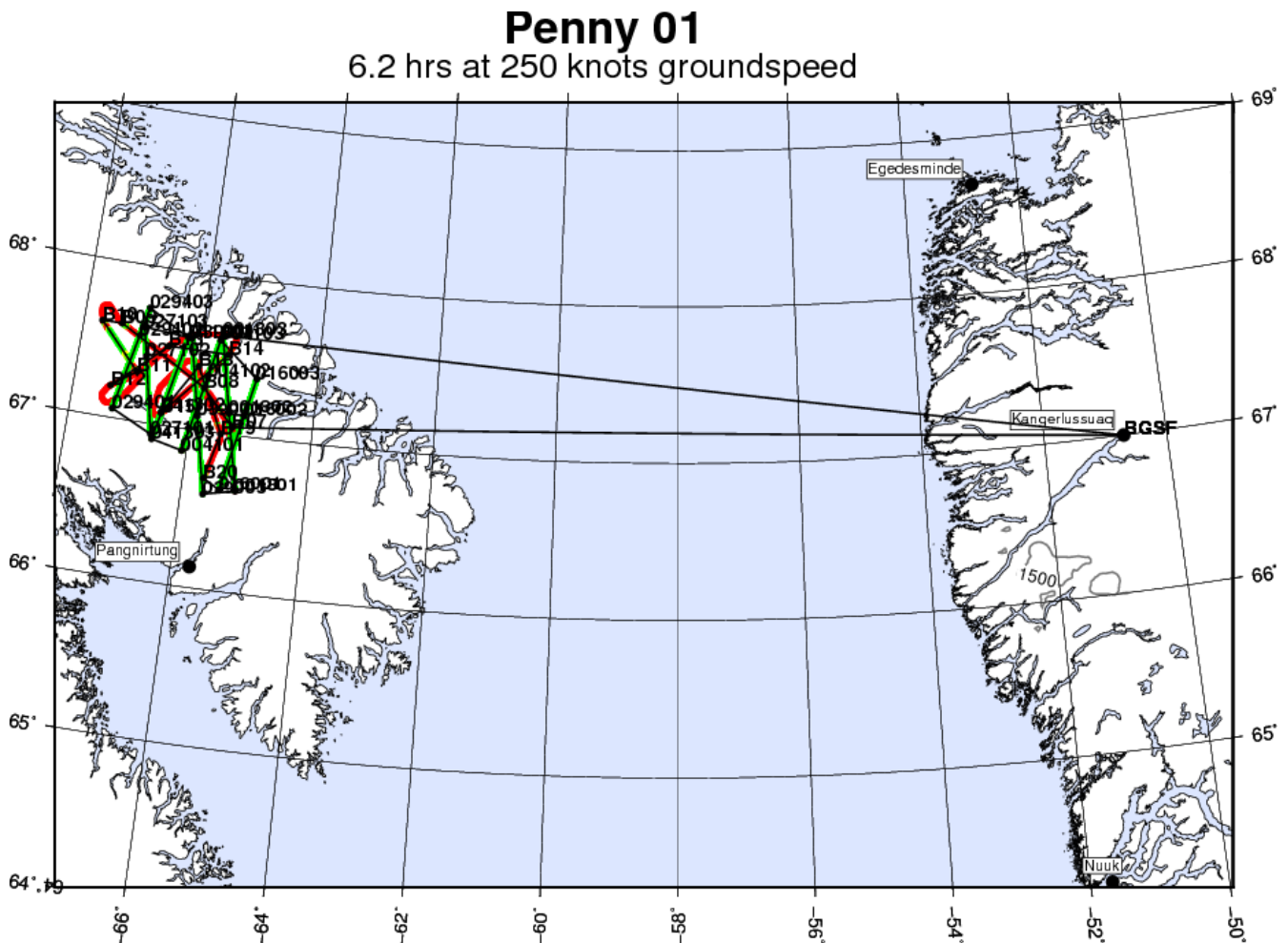
This mission repeats survey lines over the Penny Ice Cap previously surveyed by the ATM/KU teams in 1995, 2000, and 2005, and adds several new lines along ICESat ground tracks over the ice cap.

**Flight Priority:** low (multi-year repeat flight)

**ICESat Track:** 0160/0041/0413/0294/0271/0390/0018

## Last Flown: 2017

**Remaining Design Issues:** none



# Land Ice – IceSat-2 Central / Kangerlussuaq

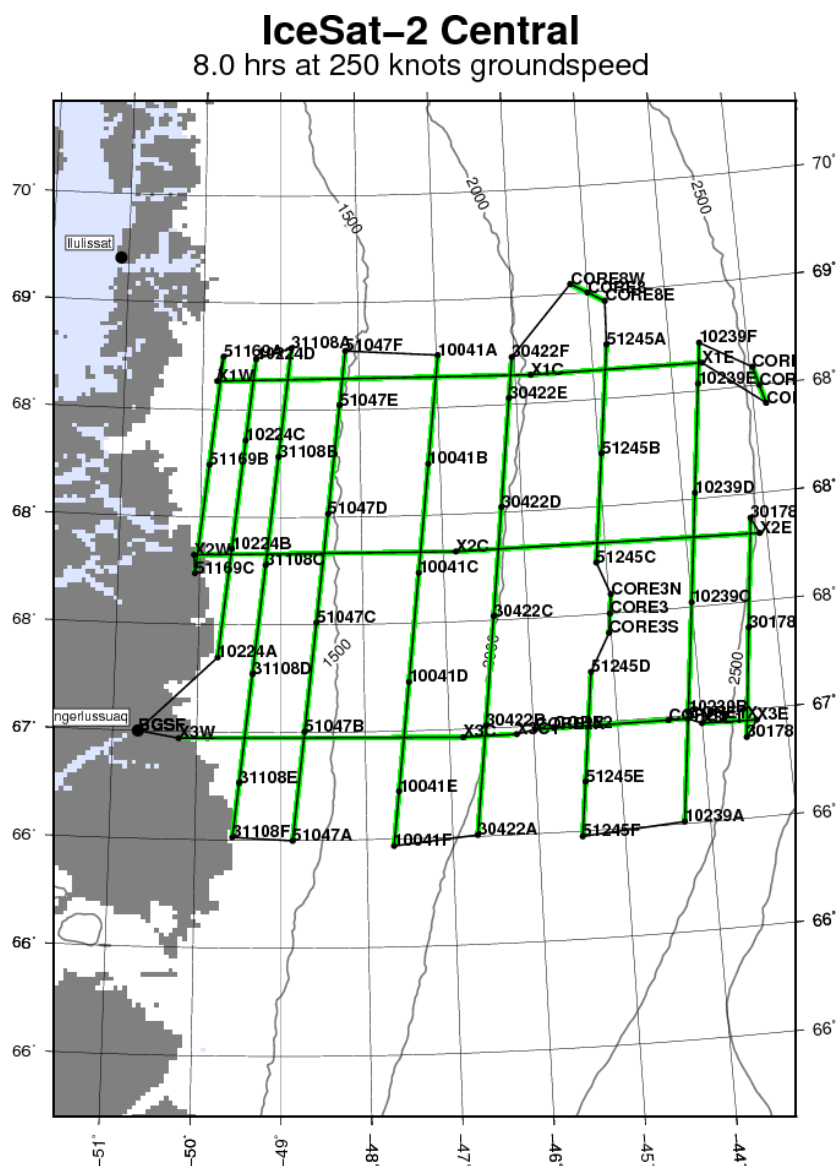
This mission was designed to overfly planned IceSat-2 ground tracks over a wide range of ice regimes near Kangerlussuaq. We center some of the flightlines on each of three beam pairs (left, nadir and right) in turn, sampling three of each beam pair during this mission. The east-west crossing lines are designed to capture as many ascending/descending crossovers as possible. We modified and augmented the mission in 2016 to overfly five GreenTrACS core sites.

**Flight Priority:** baseline (annual repeat flight)

**IceSat-2 Track:** 1169,1022,1047,0041,0422,1245,0239,0178

**Last Flown:** 2017

**Remaining Design Issues:** none

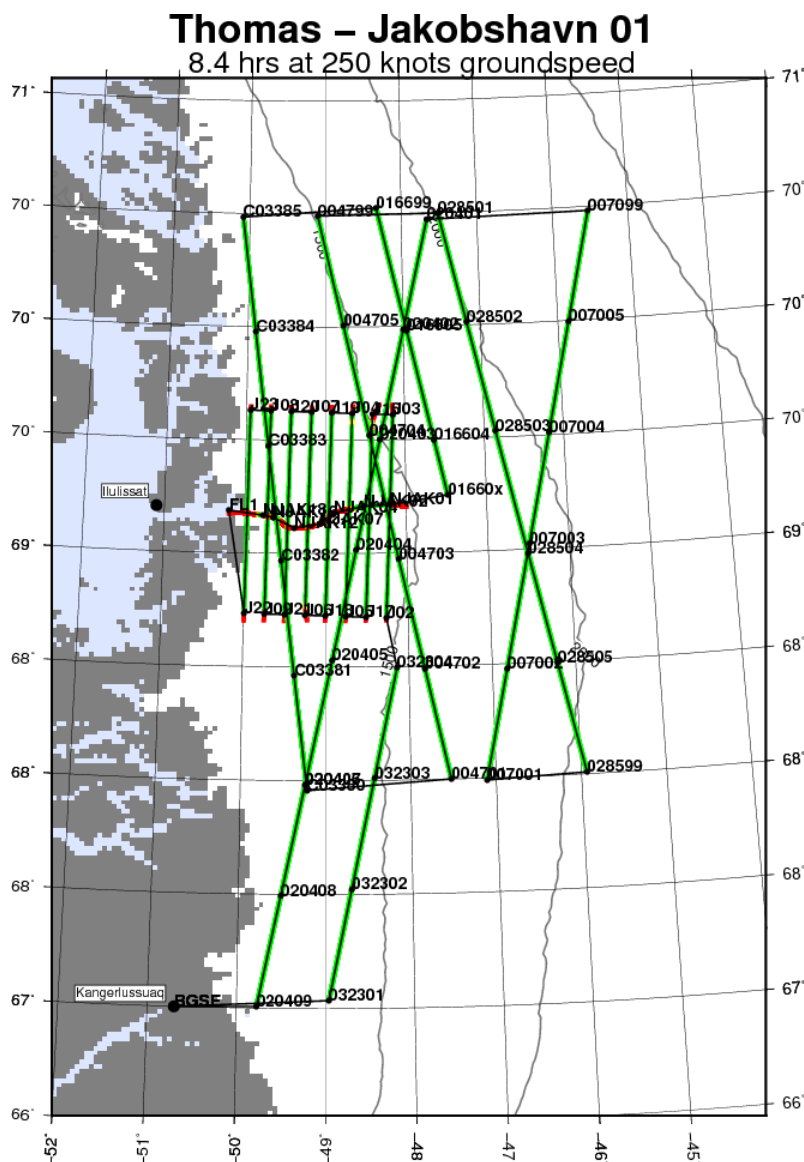


This is a repeat of 2009, 2010, 2011, 2012, 2013 and 2014 IceBridge missions. Its purpose is to re-survey the highest-priority lines of the historical ATM 10-km Jakobshavn grid, the main flowline of Jakobshavn. It also extends that grid with a broader array of ICESat ground tracks over the larger Jakobshavn basin. Renamed in 2015 in honor of Robert H. Thomas. For 2019 we replace one of the previously-flown lines with a low-latency ICESat-2 track (occupied by IS-2 on 20 April 2019). The previously-flown lines are depicted in green below, the new one in black.

**ICESat-1 Tracks:** 0323,0047,0285,0070,0204

## Last Flown: 2018

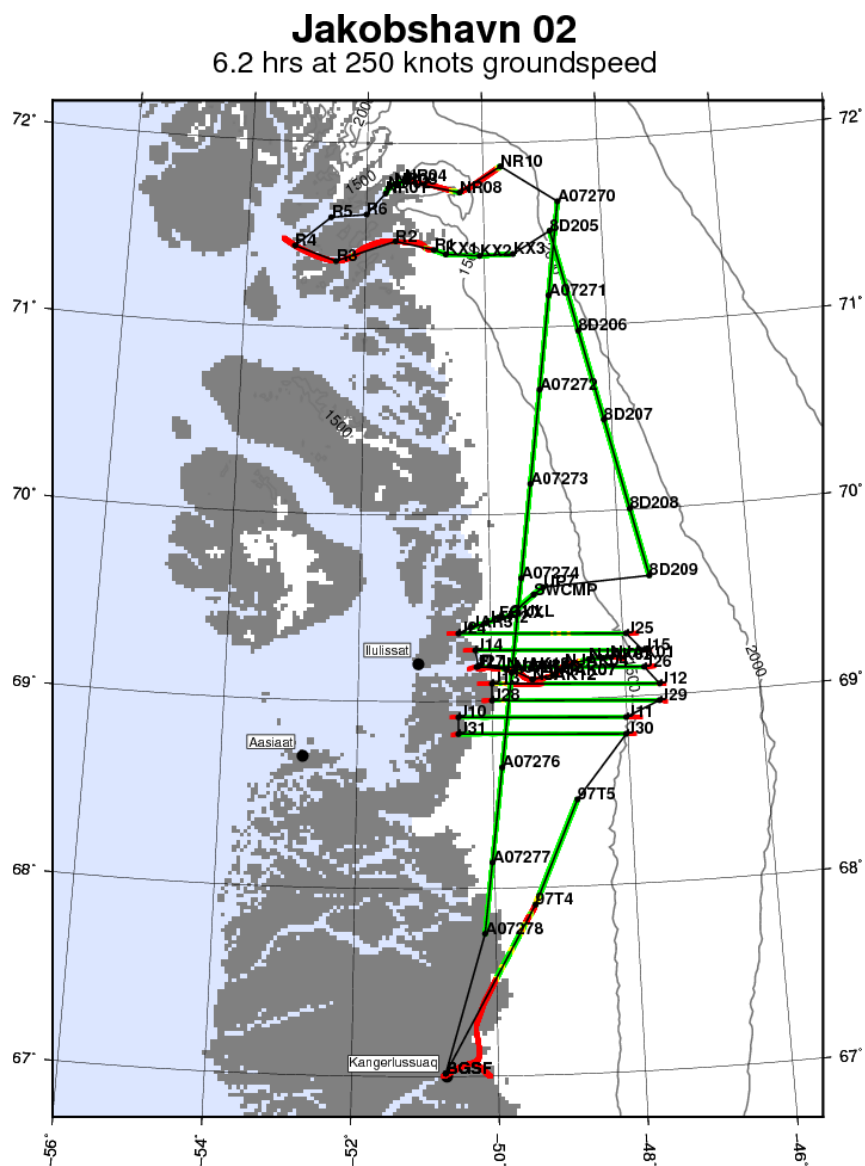
**Remaining Design Issues:** replace any of the lines with lower-latency IS-2 tracks if available



This mission is a repeat of similar 2009, 2010, 2011, 2012, 2013 and 2014 OIB flights. The primary science objectives are to (a) complete the basic Jakobshavn grid, specifically the east-west lines, and (b) repeat longitudinal surveys of the Rink and Kangerdlugssup Glaciers. We also occupy a line connecting Swiss Camp and a pair of Eric Lutz-requested points nearby. Finally we fly the main Jakobshavn centerline twice, once at normal speed and altitude, and again as low and slow as possible, for MCoRDS radar assessment. We also include centerlines of Rink and Kangerdlugssup Glaciers, which can be eliminated if these glaciers were flown as part of the Jakobshavn-Eqip-Store flight. For 2019 we replace ICESat-1 line 0085 with ICESat-2 line A0727, which is occupied by the spacecraft on 15 May 2019.

**ICESat-2 Track: A0727**

**Remaining Design Issues:** replace IS-2 A0727 line with a lower-latency track if one is available



# Land Ice – Jakobshavn-Eqip-Store / Kangerlussuaq

This is a modified version of the 2011 Jakobshavn-Lake mission, whose main purpose it to extend the ICESat grid begun with Jakobshavn 01 farther upstream. We also densify the ICESat grid over the Eqip Sermia catchment area north of Jakobshavn, and we refly the centerlines of Eqip Sermia, Kangilerngata Sermia, Sermeq Kujalleq and Store Glaciers. Finally we refly the Rink and Kangerdlugssup centerlines. For 2019 we replace two of the previously-flown lines with low-latency ICESat-2 tracks (occupied by IS-2 on 20 April and 11 May 2019). We also make a slight adjust to refly an upstream turning approach to Eqip Sermia from 2013 over a subglacial feature, at the request of Robin Bell.

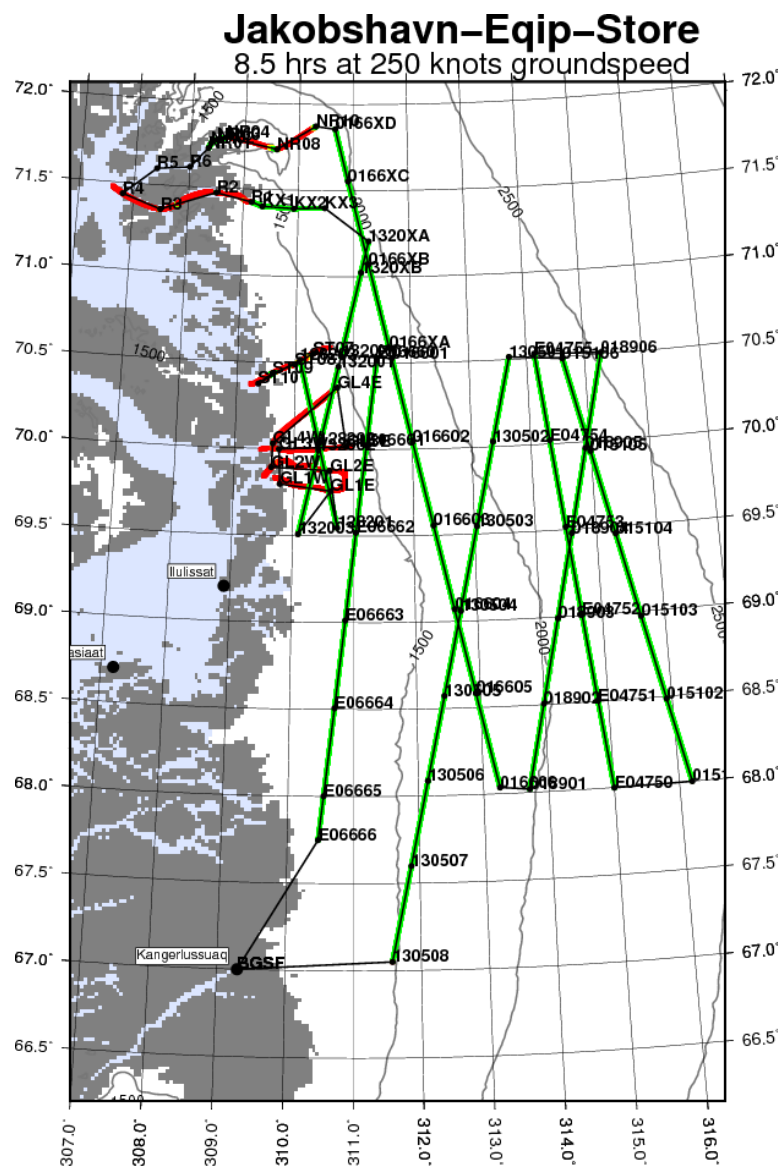
**Flight Priority:** baseline (annual repeat flight)

**ICESat-1 Tracks:** 1320,1282,0166,0189,0151,1305

**ICESat-2 Tracks:** E0666,E0475

**Last Flown:** 2017 (two upper lines in 2018)

**Remaining Design Issues:** replace any of the lines with lower-latency IS-2 tracks if available



# Land Ice – ICESat-2 Disko-Umanaq / Kangerlussuaq

This is a new mission for 2019, designed to sample the left and right beam pairs of ICESat-2 over undulating bare rock and small ice caps in Disko Island and the Umanaq Peninsula. The intention is to validate the geolocation of ICESat-2 footprints. The pattern of ICESat-2 ground tracks is nearly repeated, targeting the left beam pair on one pass and the right pair on the other. We validate range biases on the center beam pair during other missions.

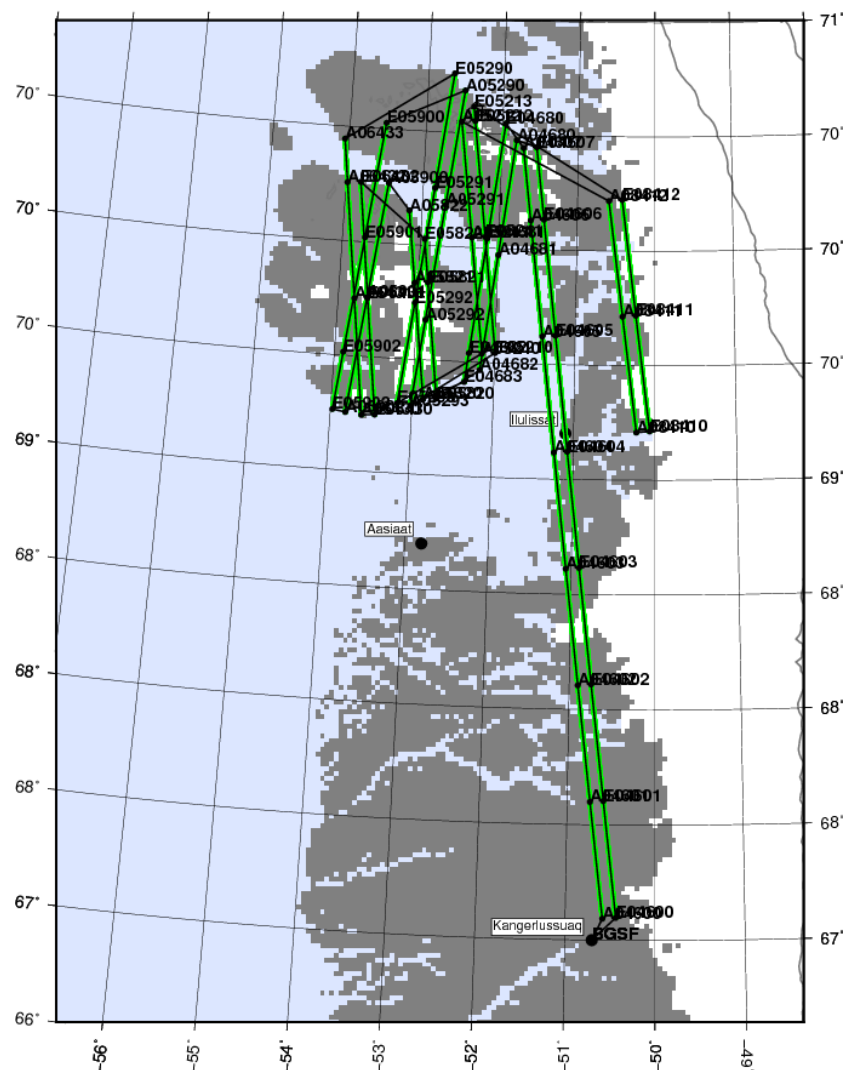
**Flight Priority:** low

**ICESat-2 Tracks:** A0460,E0460,A0468,E0468,A0582,E0582,A0590,E0590,A0529,E0529,A0521,E0521,A0841,E0841,A0643,E0643

**Last Flown:** new flight

**Remaining Design Issues:** none

## ICESat-2 Disko-Umanaq 8.0 hrs at 250 knots groundspeed



# Land Ice – Umanaq B / Kangerlussuaq

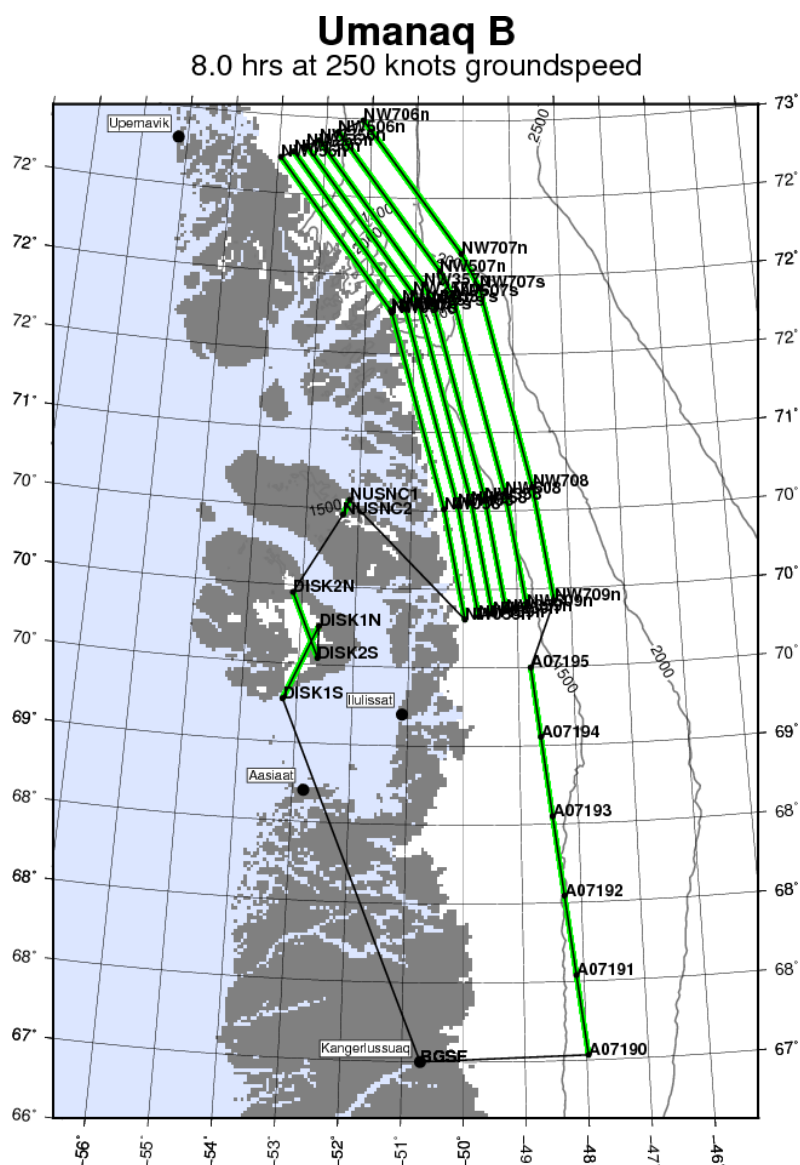
This mission is designed (along with Umanaq A) to refly the 2012 Umanaq coast-parallel grid with a pair of interlaced missions. This mission by itself reoccupies a grid spaced at 10 km near the coast, widening to 20 km upstream. The two flights together establish a grid at half this spacing. We also refly a pair of 2012 lines over the Disko Island ice cap, and another 2016 line over the Nuussuaq Peninsula. For 2019 we replace ICESat-1 line 0419 with ICESat-2 line A0719, which is occupied by the spacecraft on 15 May 2019.

**Flight Priority:** high (multi-year repeat flight)

**ICESat -2 Track:** A0719

**Last Flown:** 2017

**Remaining Issues:** replace IS-2 A0719 line with a lower-latency track if one is available



# Land Ice – East Glaciers 01 / Kangerlussuaq

This mission maps the centerlines of several glaciers on the central east coast of Greenland. This particular draft captures the centerlines of six glaciers: DeGeer, Jaette, Nordenskiold, Wahlenberg, Violin and Nord Glaciers. The first two were originally flown during the 2009 OIB campaign, and all were flown in 2012. The Violin centerline passes within 1 km of two PROMICE sites. For 2019 we add overpasses of three lines targeted across the uppermost portion of the north Greenland subglacial canyon, near Summit, at the suggestion of Chris Chambers. We return to Kangerlussuaq along a low-latency ICESat-2 line.

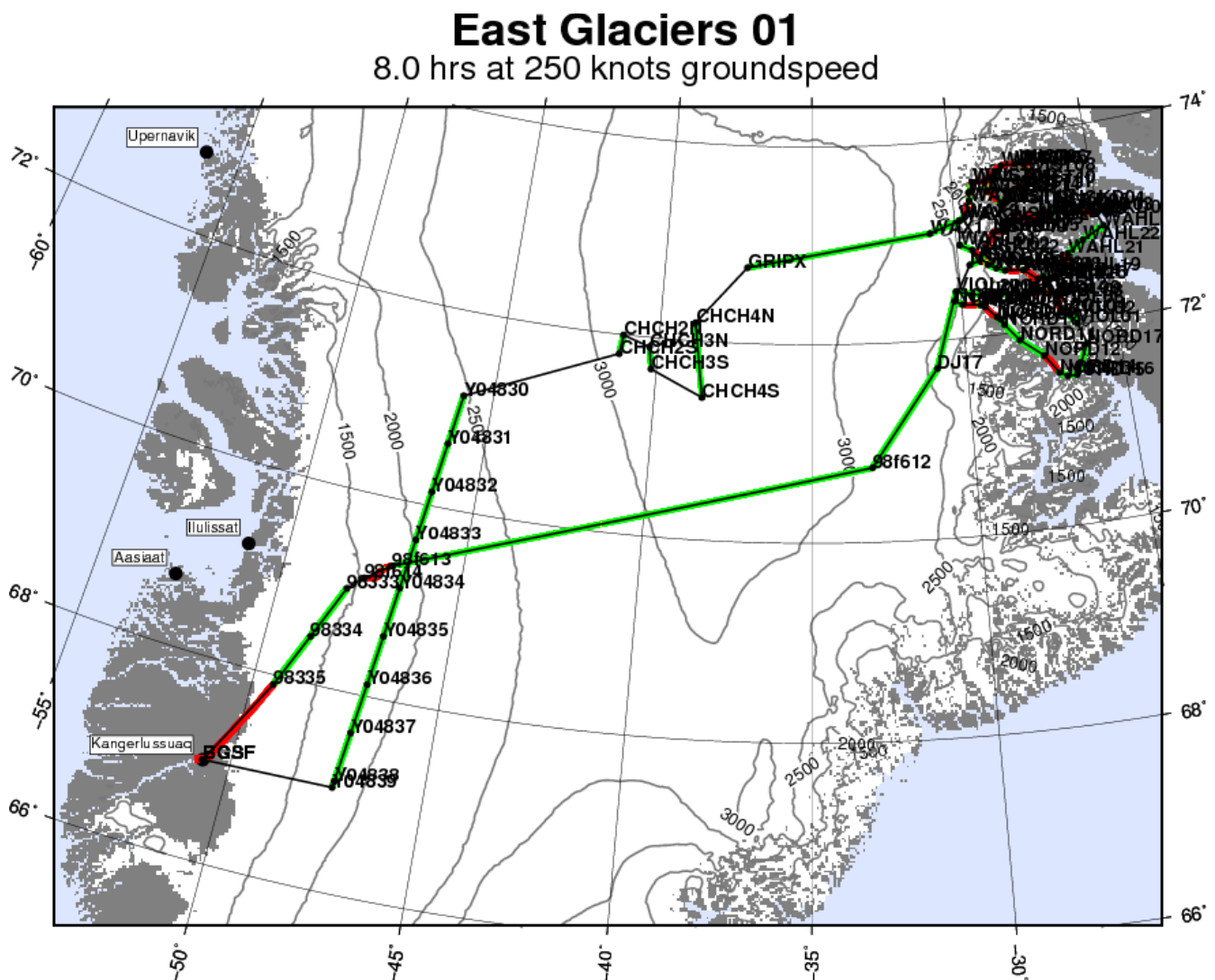
**Flight Priority:** low (multi-year repeat flight)

**ICESat-1 Track:** 0412

**IceSat-2 Tracks:** Y0483

**Last Flown:** 2018

**Remaining Issues:** none



# Land Ice – K-EGIG-Summit / Kangerlussuaq

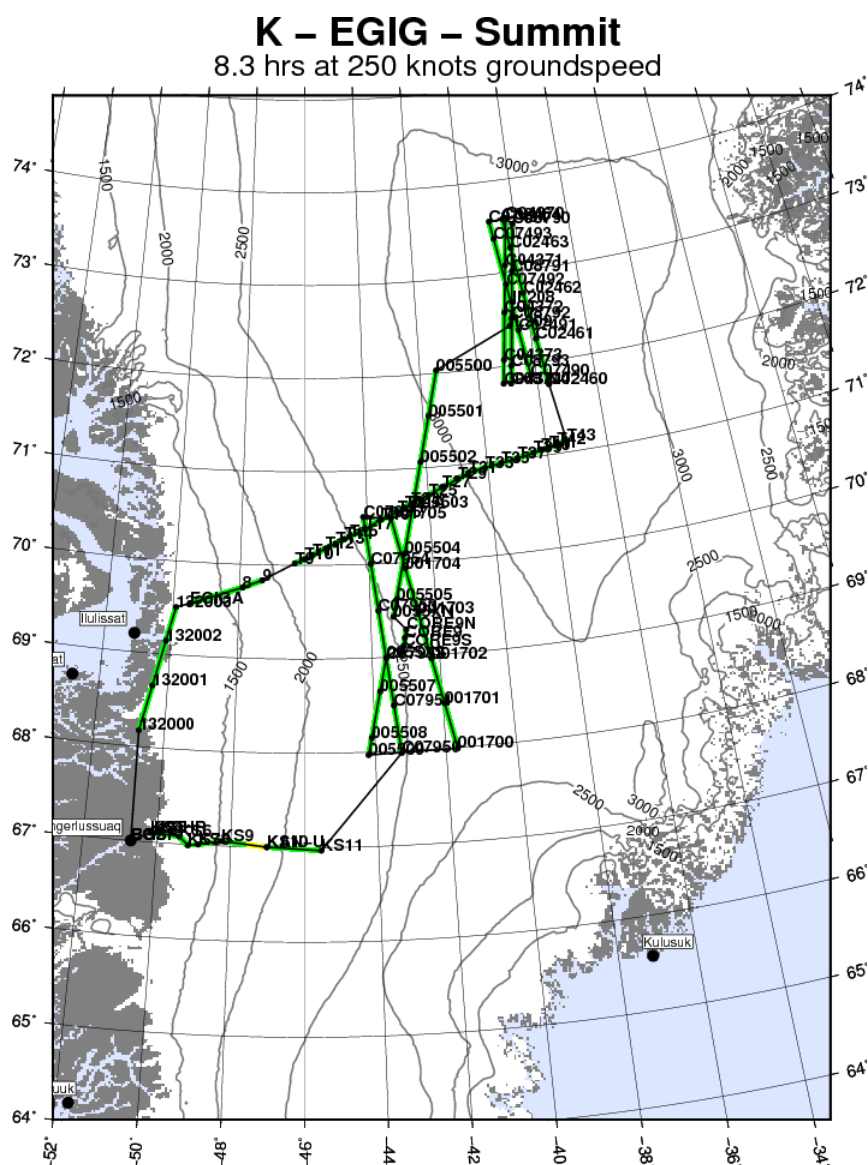
This mission was designed to accomplish a number of high-priority tasks. First, we re-fly the van den Broeke “K-Transect” in the Russell Glacier catchment, consisting of several sites where comprehensive glaciological measurements are collected annually. We also fly the EGIG traverse line, which is expected to be occupied as part of the CryoVex effort in spring 2019. We overfly the IceSat-1 track 412 Summit calibration site. For 2016, we add an overflight of a GreenTrACS core near IceSat track 0055. Finally we extend the coverage of the Jakobshavn basin upstream along IceSat-1 tracks, to capture continued inland progression of thinning there. For 2019 we replace one of the previously-flown upper Jakobshavn lines with a low-latency ICESat-2 track (occupied by IS-2 on 20 May 2019). We also remove the eastern portion of the EGIG line, replacing it with extended IS-2 ground tracks around Summit.

**Flight Priority:** baseline (annual repeat flight)

**Satellite Tracks:** 0017,0055,0412,1320 (IS-1), C0795,C0879,C0437,C0749,C0246 (IS-2)

**Last Flown:** 2018

**Remaining Design Issues:** replace any of the lines with lower-latency IS-2 tracks if available



# Land Ice – East-Central Bed Gap IS-2 / Kangerlussuaq

This mission was designed with two goals in mind. First, it (along with the Thule-based West-Central Bed Gap 01 flight) are designed to address the largest gaps in knowledge of the bedrock geometry still existing in Greenland. This flight does so along carefully-selected segments of two master grid lines and three low-latency ICESat-2 tracks. In addition, this flight addresses the onset region of the Northeast Greenland Ice Stream with a repeat of a 1997 line on its eastern margin, a new line along its centerline, and a repeat of a 1994 crossing line.

**Flight Priority:** medium

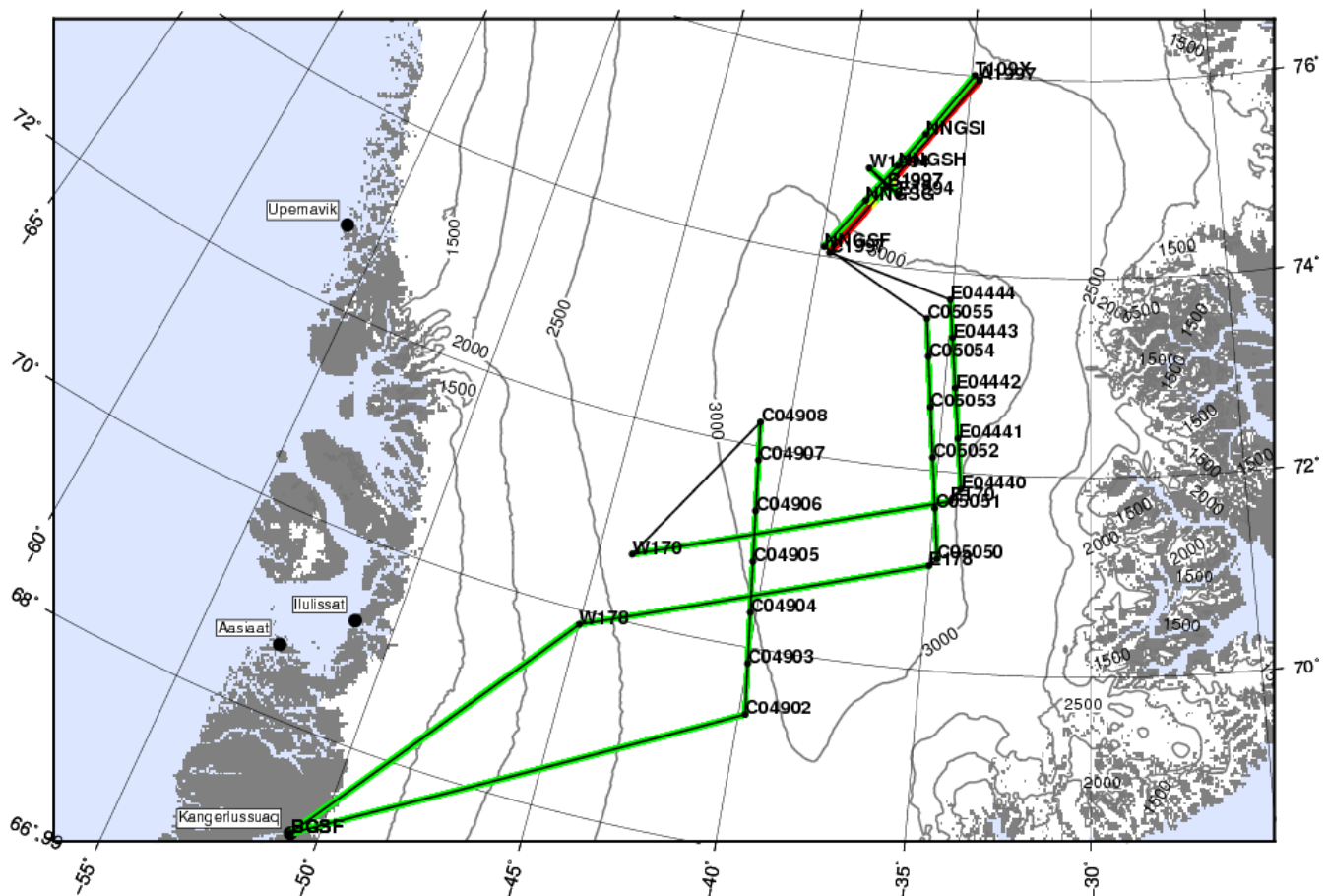
**ICESat Track:** C0490,C0505,E0444

**Last Flown:** new mission

**Remaining Design Issues:** none

## East-Central Bed Gap IS-2

8.1 hrs at 250 knots groundspeed



# Land Ice – Geikie 01 / Kangerlussuaq

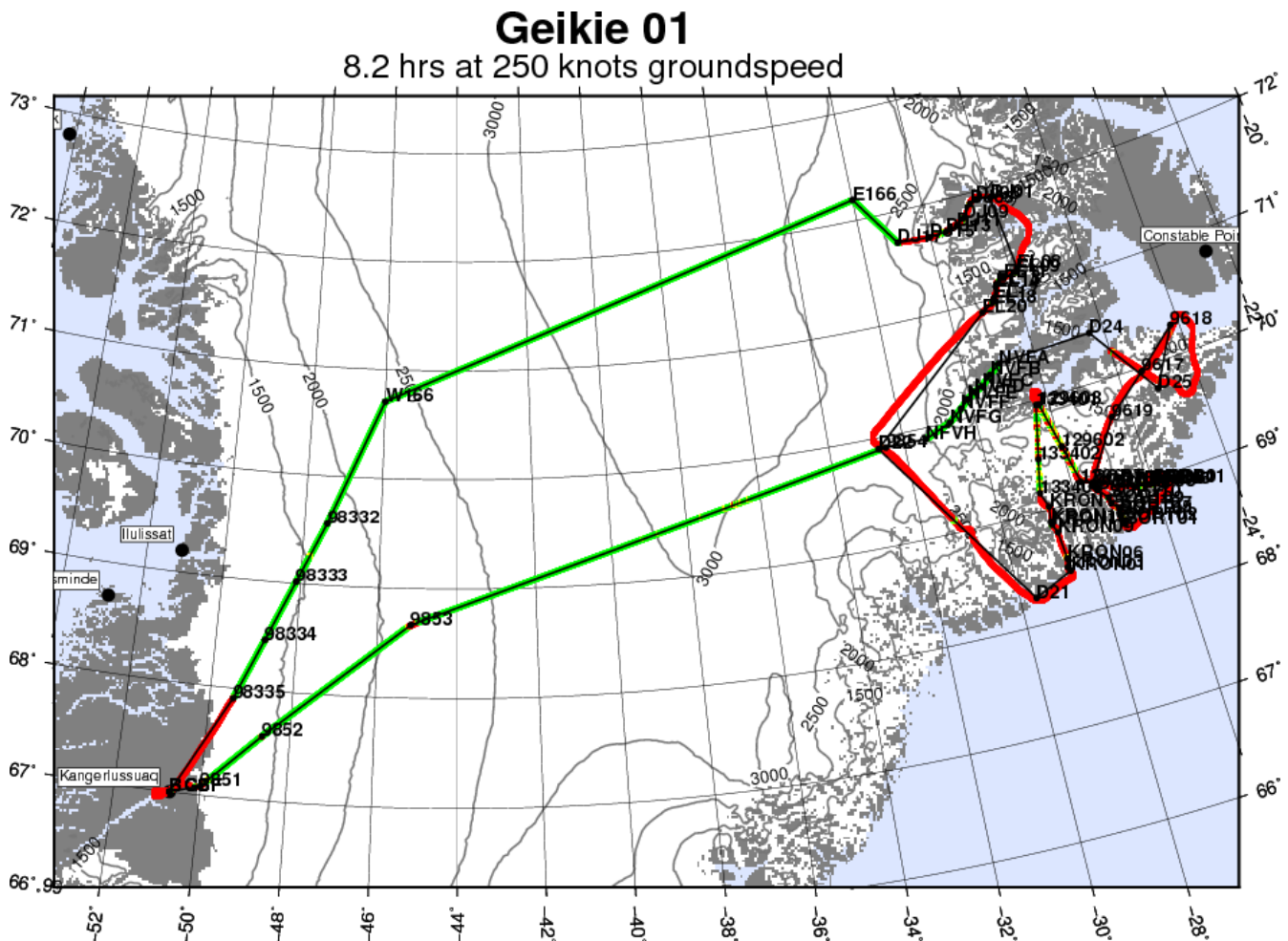
This mission is a repeat of 2010, 2011 and 2014 IceBridge missions. It includes reflights of the Daugard-Jensen, Vestfjord and Kong Christian IV glaciers, and the “X” pattern over the Geikie Plateau, all of which have pre-IceBridge altimetry from ATM. It also reflies the Eielson, De Reste Bugt, Sortebrae and Kronborg glaciers, first flown in 2010. Finally, the northern transit line across the ice sheet is a master grid line, which has not been flown prior to 2014.

**Flight priority:** medium (multi-year repeat flight)

**ICESat Track:** none

**Last Flown:** 2017

**Remaining Design Issues:** none



# Land Ice – Geikie 02 / Kangerlussuaq

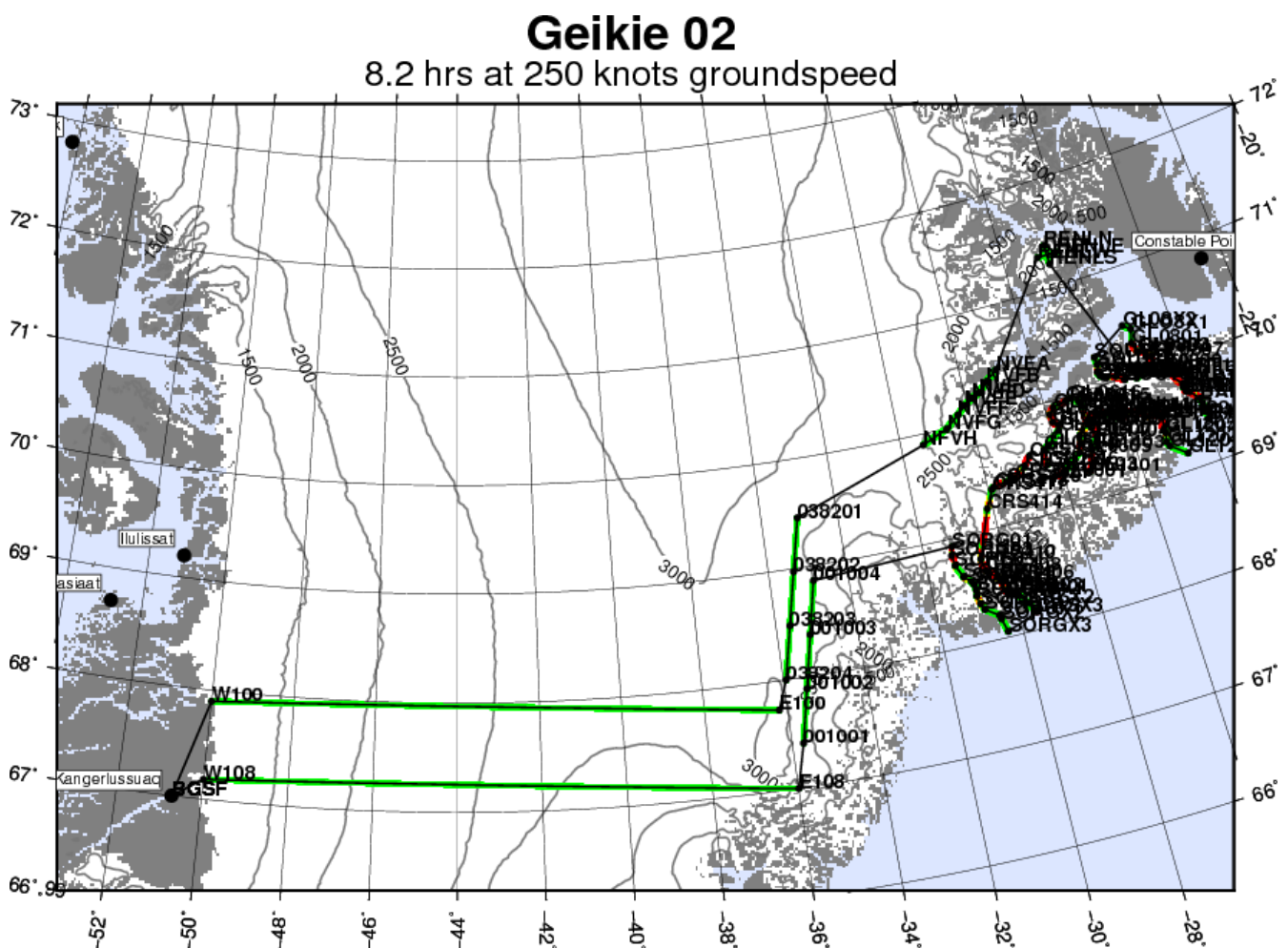
This mission flies the centerlines of eight Geikie peninsula glaciers. These are Sorgenfri, Christian IV, Bartholins, and South glaciers, plus five more glaciers with unknown names. We transit to and from the Geikie area along master grid lines and IceSat-1 ground tracks. For 2015 we added a crossing of a proposed core site on the Renland ice cap, plus an improved centerline of the Vestfjord Glacier. For 2018 we replace the east-west crossing lines with new lines from the master grid, selected to fill in gaps in bedrock knowledge.

**Flight Priority:** low (multi-year repeat flight)

**ICESat Track:** 0010,0382

**Last Flown:** 2018

**Remaining Design Issues:** none



Land Ice – Helheim-Kangerdlugssuaq Gap B /  
Kangerlussuaq

This mission is designed (along with Helheim-Kangerdlugssuaq Gap A) to re-fly a 2012 grid over the area of complex terrain between the Helhim and Kangerdlugssuaq Glaciers. Each of these new missions alone forms a coast-parallel grid spaced at 20 km, and the two flights together interlace to form a 10-km grid. This particular mission also reoccupies the centerlines of two glaciers in the area (names unknown). For 2019 we modify the east-west crossings to target low-latency IS-2 crossover latitudes.

**Flight Priority:** high (multi-year repeat flight)

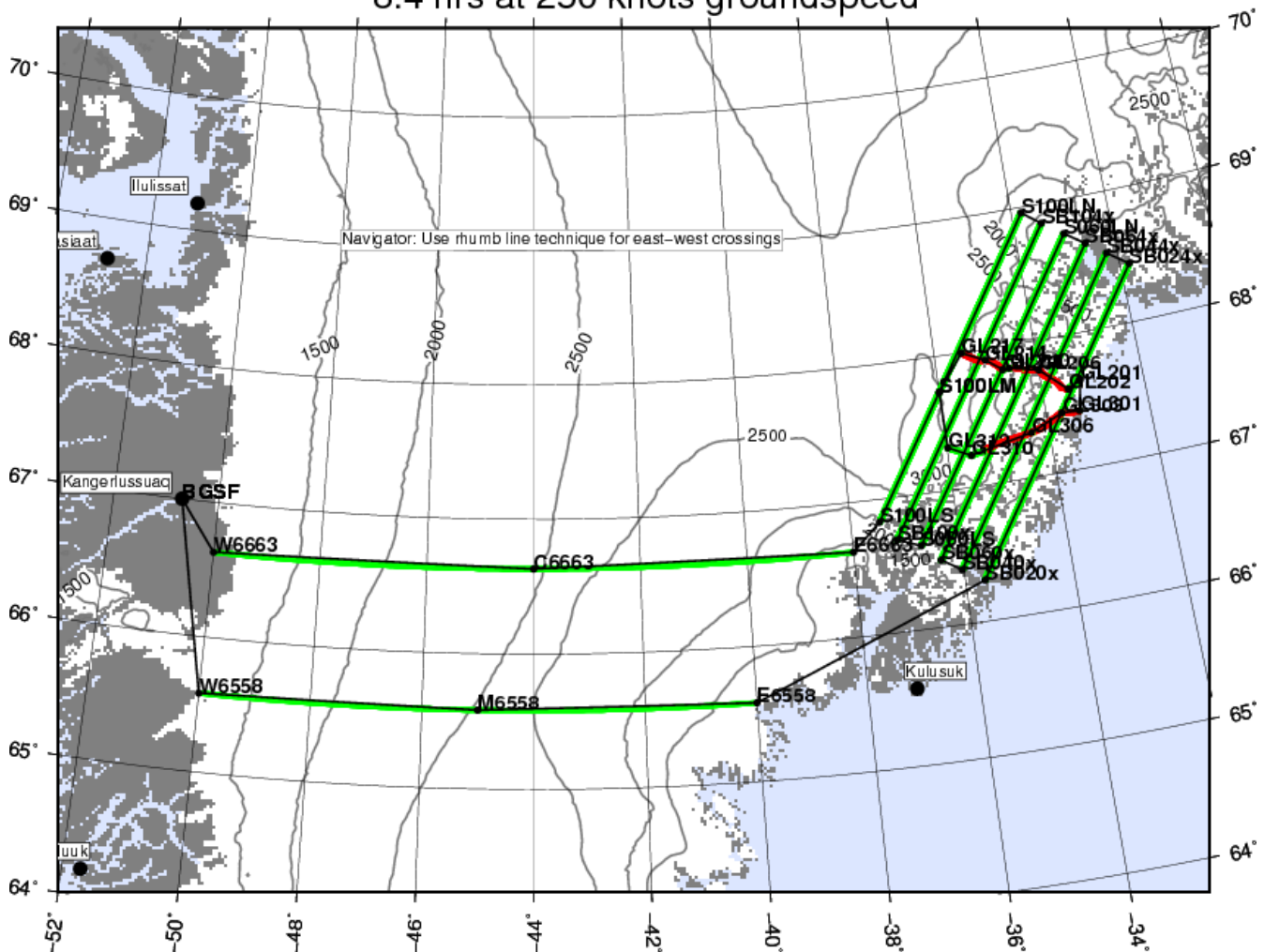
**ICESat Track:** none

## Last Flown: 2017

**Remaining Design Issues:** none

## Helheim-Kangerdlugssuap Gap B

8.4 hrs at 250 knots groundspeed



# Land Ice – Helheim-Kangerdlugssuaq / Kangerlussuaq

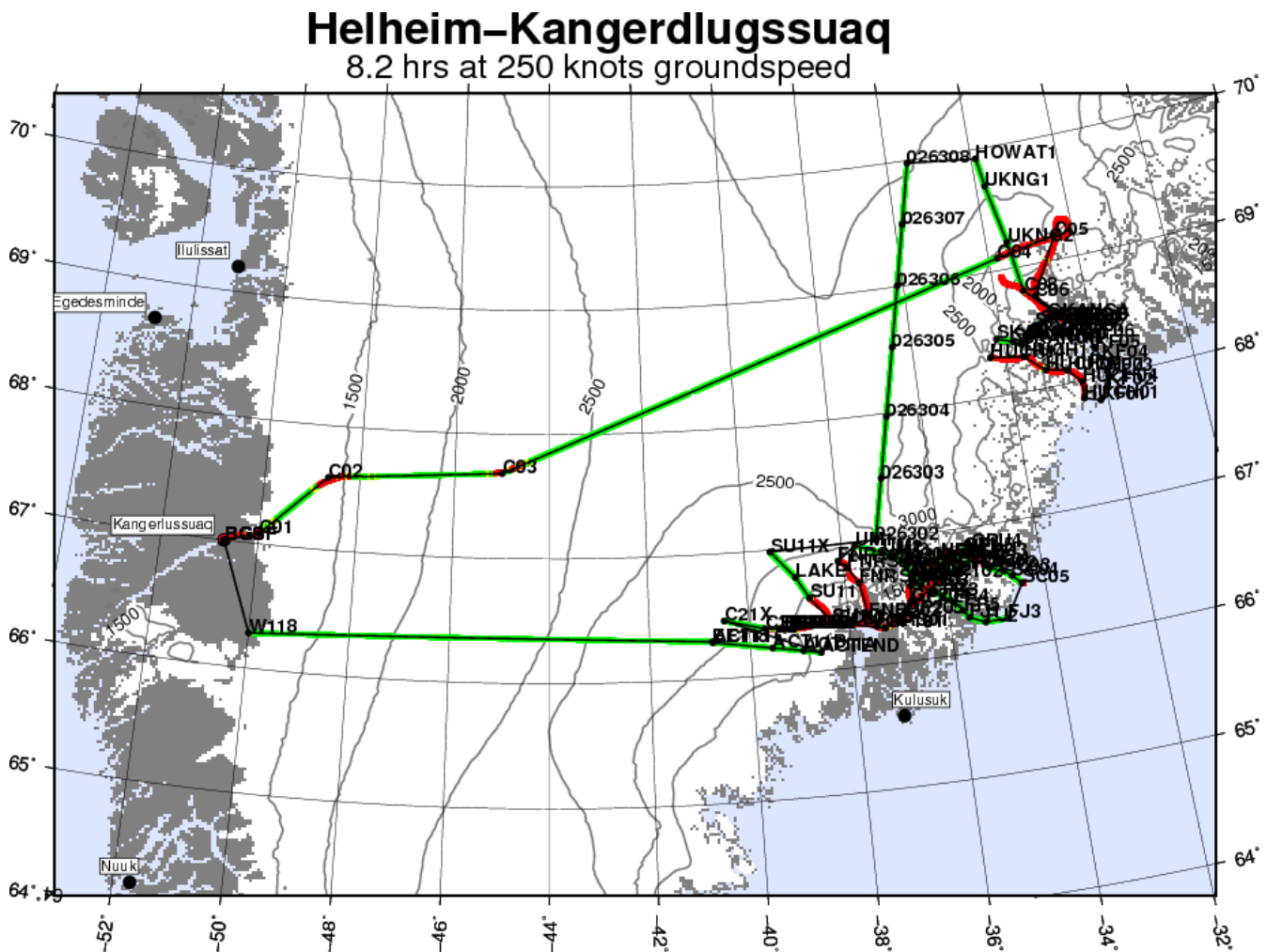
This is a repeat mission, and is very similar to missions flown in 2010, 2011, 2012 and 2013. It captures centerline surveys of the two main branches of Helheim, of Kangerdlugssuaq, Fenris and of several branches of Midgard glaciers. We also re-fly the centerline of the Hutchinson Glacier, and establish a new centerline of a glacier which empties into the fjord of Kangerdlugssuaq Glacier just beyond its terminus. For 2018 we extend the main (northwest) and west centerlines of Helheim Glacier to above the 2000m contour line.

**Flight Priority:** high (annual repeat flight prior to 2019)

**ICESat Track:** 0263

**Last Flown:** 2018

**Remaining Design Issues:** none



# Land Ice – OSU Clusters / Kangerlussuaq

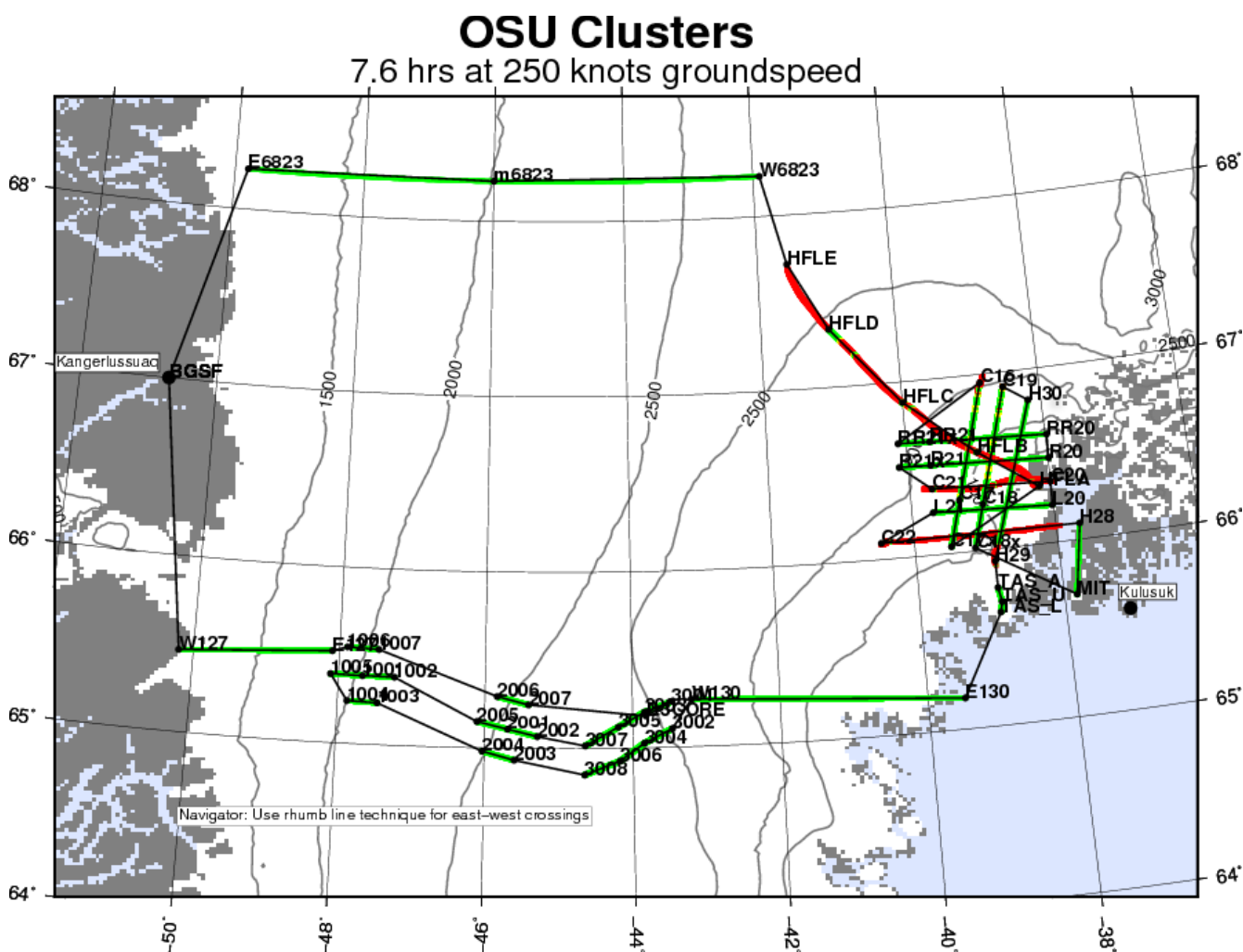
This mission was designed with several goals in mind. First, we re-fly the OSU Cluster sites straddling the ice divide southeast of Kangerlussuaq. We also fly a centerline of Helheim Glacier from the terminus all the way to the ice divide, and we re-fly a ~15-km grid pattern over the lower Helheim catchment last flown by the ATM/KU teams in 2008. Finally we overfly four PROMICE sites straddling the mouth of Sermilik Fjord, and we overfly the DYE-3 core. For 2017 we slightly redesigned the mission to remove the uppermost NS Helheim grid line, replacing it with master grid lines connecting the Cluster sites with the eastern and western ice margins. For 2019 we replace the northern master grid east-west crossing with a low-latency IS-2 crossover line.

**Flight Priority:** medium (multi-year repeat flight)

**ICESat Track:** 0040,0181

**Last Flown:** 2014

**Remaining Design Issues:** none



# Land Ice – Southeast Coastal / Kangerlussuaq

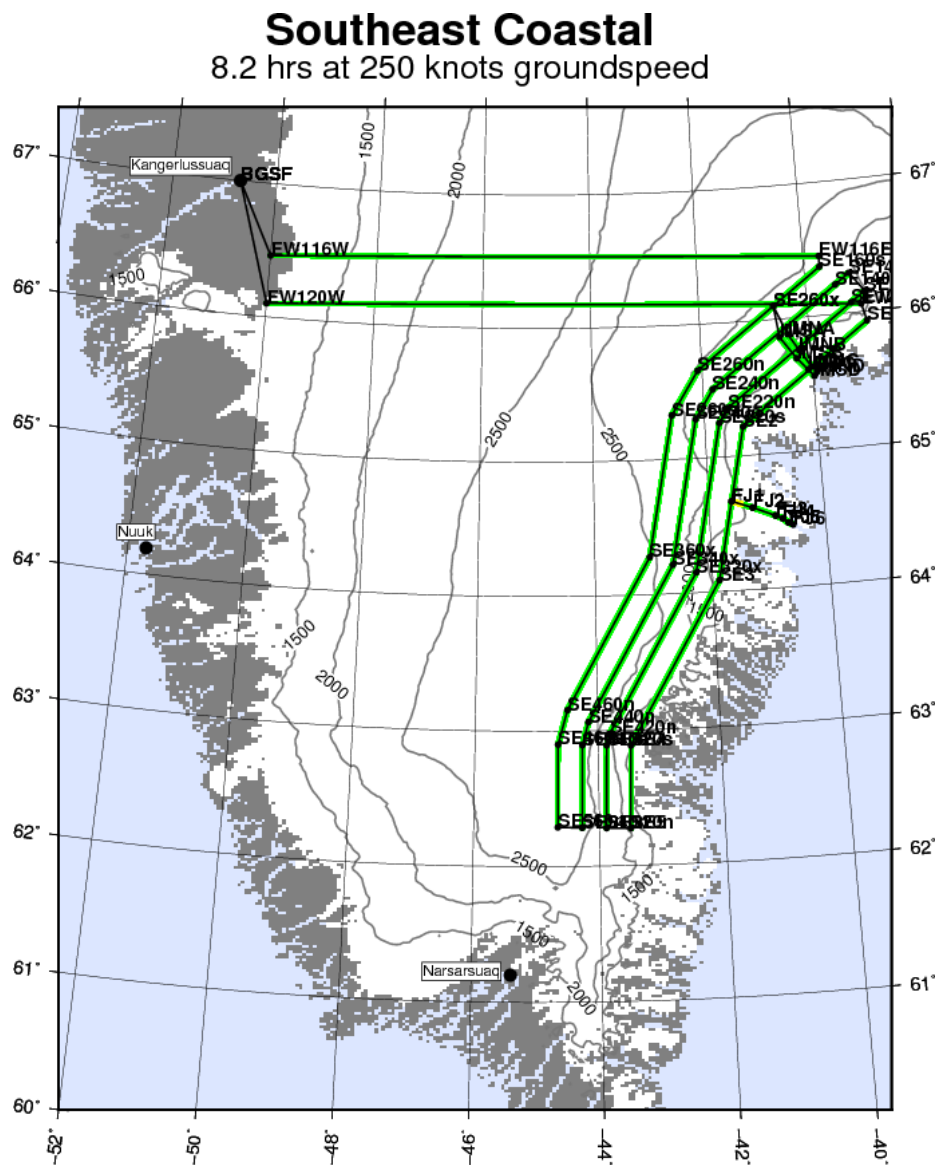
This mission reflyes a 20-km coast-parallel grid along the southeast Greenland coast, enabling direct measurement of  $dh/dt$  in the catchment areas of the many major glaciers in the area across a range of surface elevations. It also reflyes the centerlines of the Fridtjof Glacier, as well as the two central branches of the Ikertivaq Glaciers. The Ikertivaq centerlines are new for 2015.

**Flight Priority:** high (annual repeat flight prior to 2019)

**ICESat Track:** none

**Last Flown:** 2018

**Remaining Design Issues:** none



# Land Ice – Southeast Flank IS-2 / Kangerlussuaq

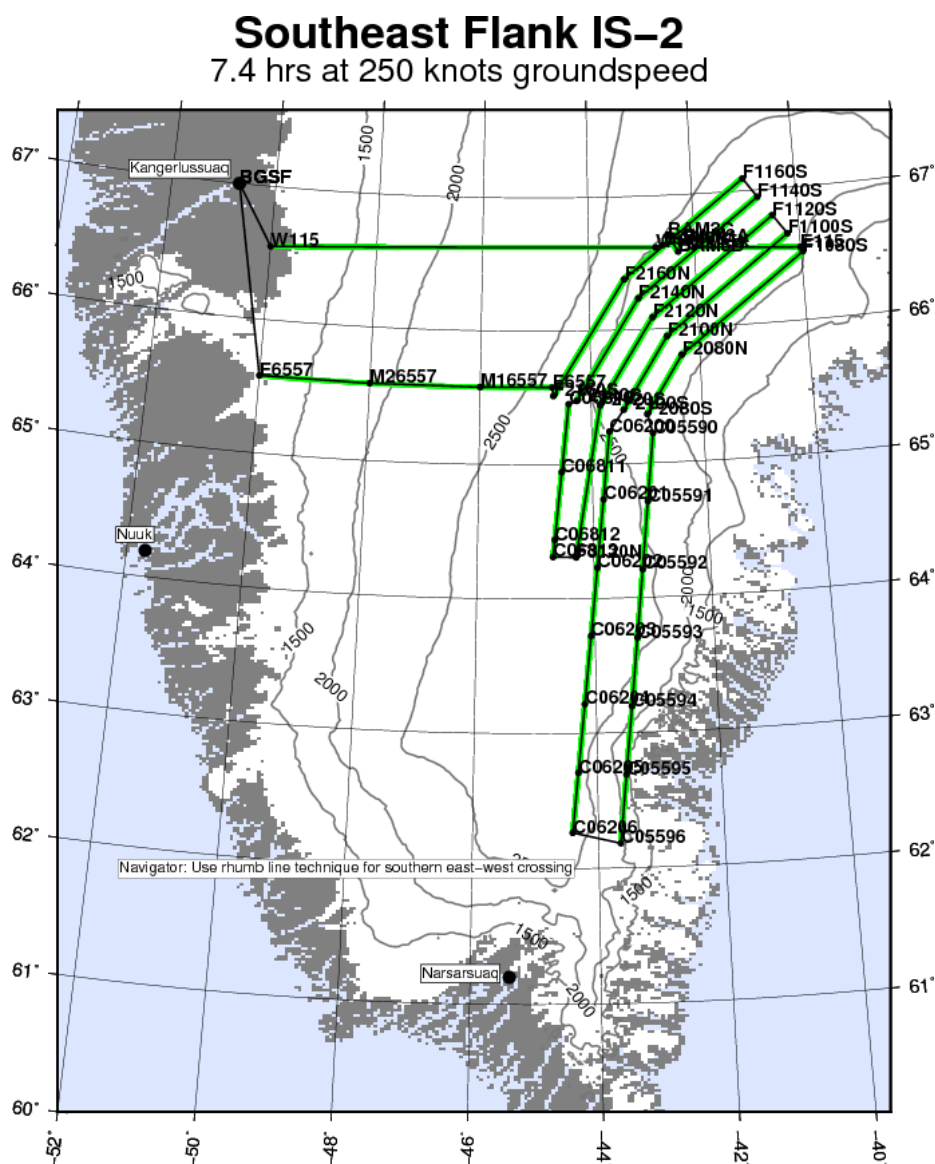
This mission reflies a 20-km coast-parallel grid along the upper southeastern flank of the ice sheet, enabling direct measurement of  $dh/dt$  in the catchment areas of the many major glaciers in the area across a range of surface elevations. It continues the  $dh/dt$  record of the Southeast Coastal mission up to the ice divide in this area. For 2017 we conduct crossing passes over a subglacial site of interest, at the request of Jon Bamber. For 2019 we replace portions of the north-south-trending lines with low-latency ICESat-2 ground tracks, and the southern of the east-west crossings with a low-latency IS-2 crossover latitude.

**Flight Priority:** medium (multi-year repeat flight)

**ICESat Track:** none

**Last Flown:** 2015

**Remaining Design Issues:** replace any lines with lower-latency IS-2 tracks if available



# Land Ice – Southeast Glaciers 01 / Kangerlussuaq

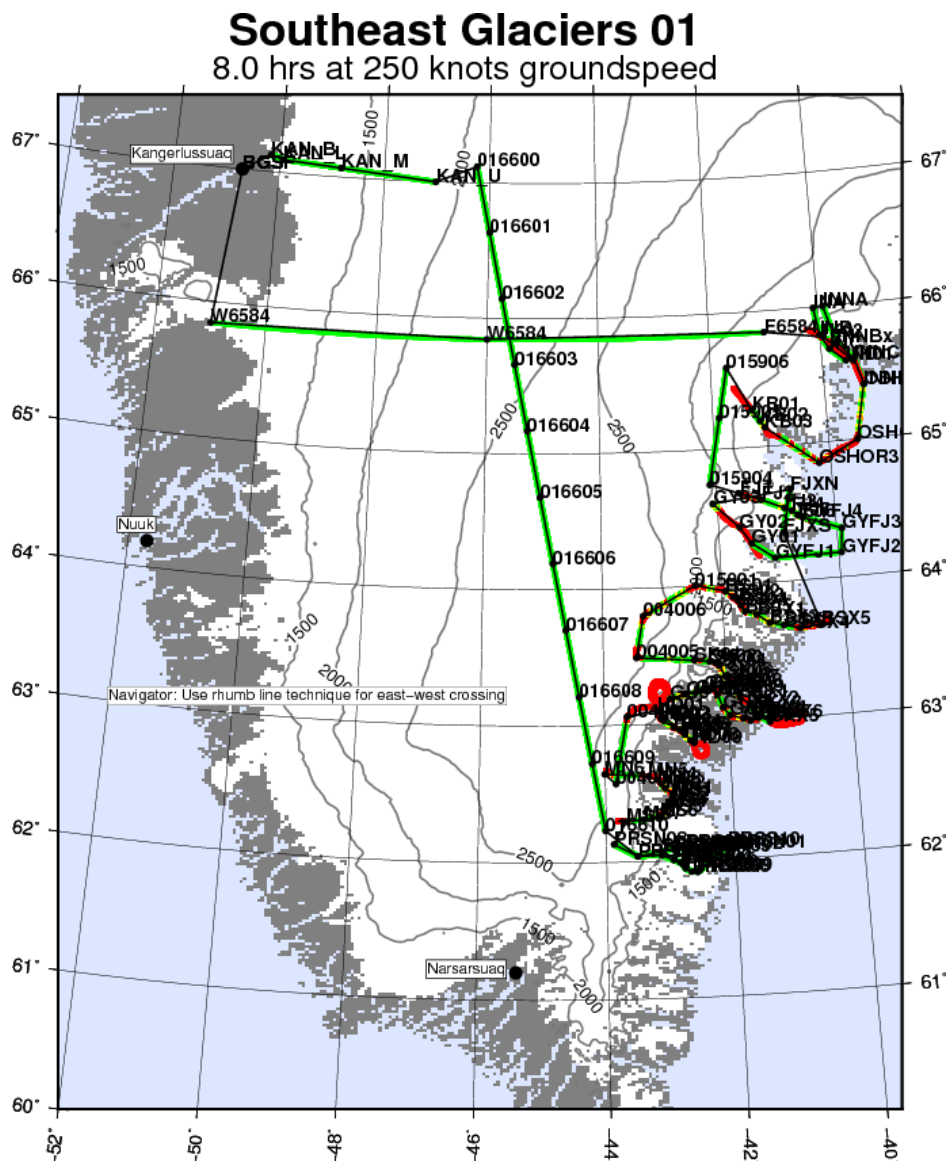
This mission is a near-repeat of the 2012/2013/2014 Southeast Glaciers mission. Its primary purpose is to continue  $dh/dt$  monitoring of 10 glaciers in the southeast which have been flown since 2008, and two additional glaciers in the south near the Pursortoq peninsula first flown in 2012. We also occupy an ICESat line between the southernmost glacier and Kangerlussuaq, and an east-west master grid line between the northernmost glacier and Kangerlussuaq. We overfly four PROMICE sites near Kangerlussuaq. For 2015 we added new lines on the Ikertivaq-N and Ikertivaq-NN channels of Ikertivaq Glacier, since the original line was not optimally placed. The original line is nevertheless retained here for  $dh/dt$  continuity purposes. This had been a baseline OIB flight, but was demoted in 2016 because of its unsuitability to be flown from high altitude during the melt season campaigns. For 2019 we modify the west-east crossing to target low-latency IS-2 crossover latitudes.

**Flight Priority:** medium (multi-year repeat flight)

**ICESat Track:** 0166,0040,0159

**Last Flown:** 2017

**Remaining Design Issues:** none



# Land Ice – Southeast Glaciers 02 / Kangerlussuaq

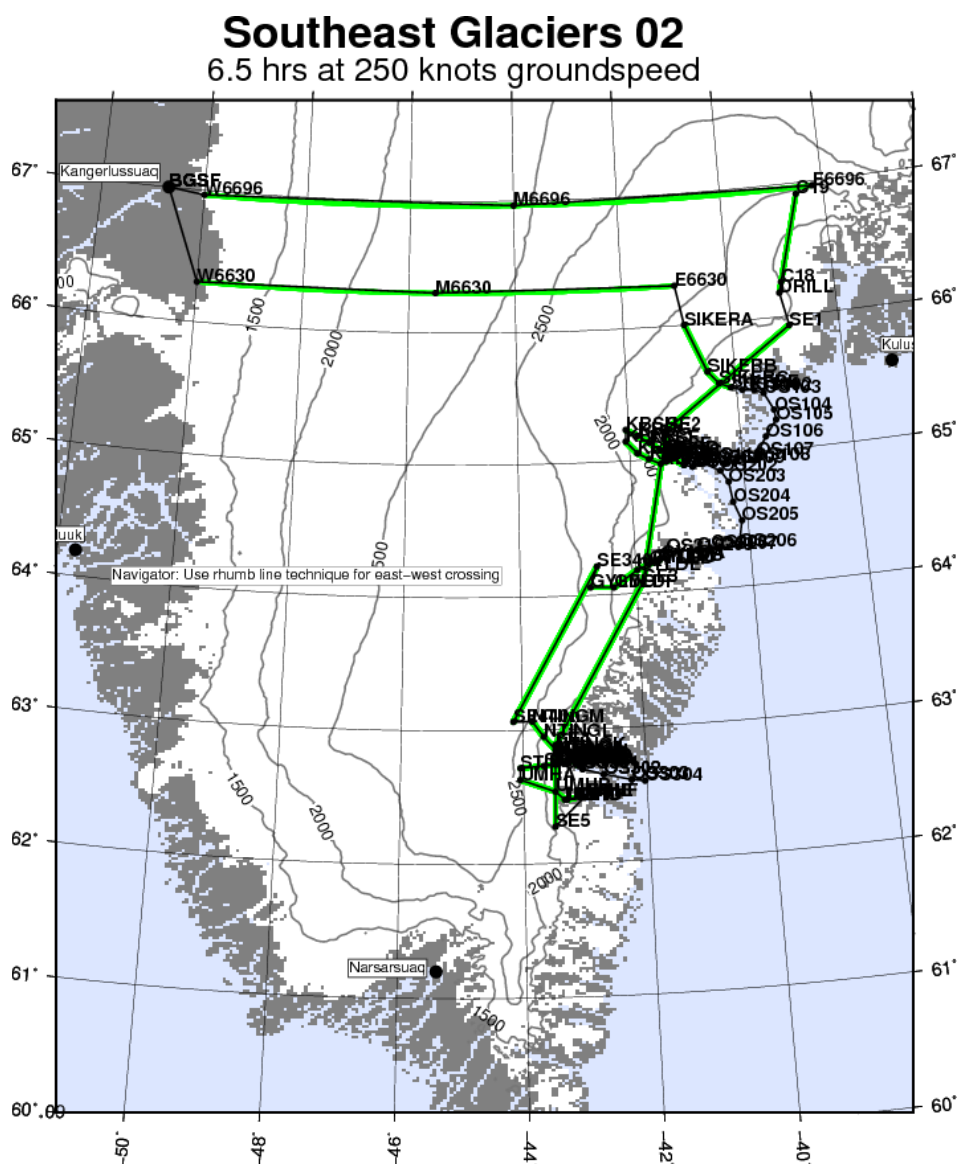
This mission is designed to fly the centerlines of the largest glaciers in the southeast not included in other OIB missions flown prior to this one. These include a southern branch of Ikertivaq, a wishbone-shaped glacier emptying into Koge Bay, Gyldenlove, the Tingmiarmiut wishbone, and an unnamed glacier emptying into Mogens-Heinesen Fjord. We transit to and from the area on new east-west master grid lines, and we transit between the glaciers on lines previously flown in the Southeast Coastal suite of missions. For 2019 we modify the east-west crossings to target low-latency IS-2 crossover latitudes.

**Flight Priority:** medium (multi-year repeat flight)

**ICESat Track:** none

**Last Flown:** 2015

**Remaining Design Issues:** none



# Land Ice – IceSat-2 South / Kangerlussuaq

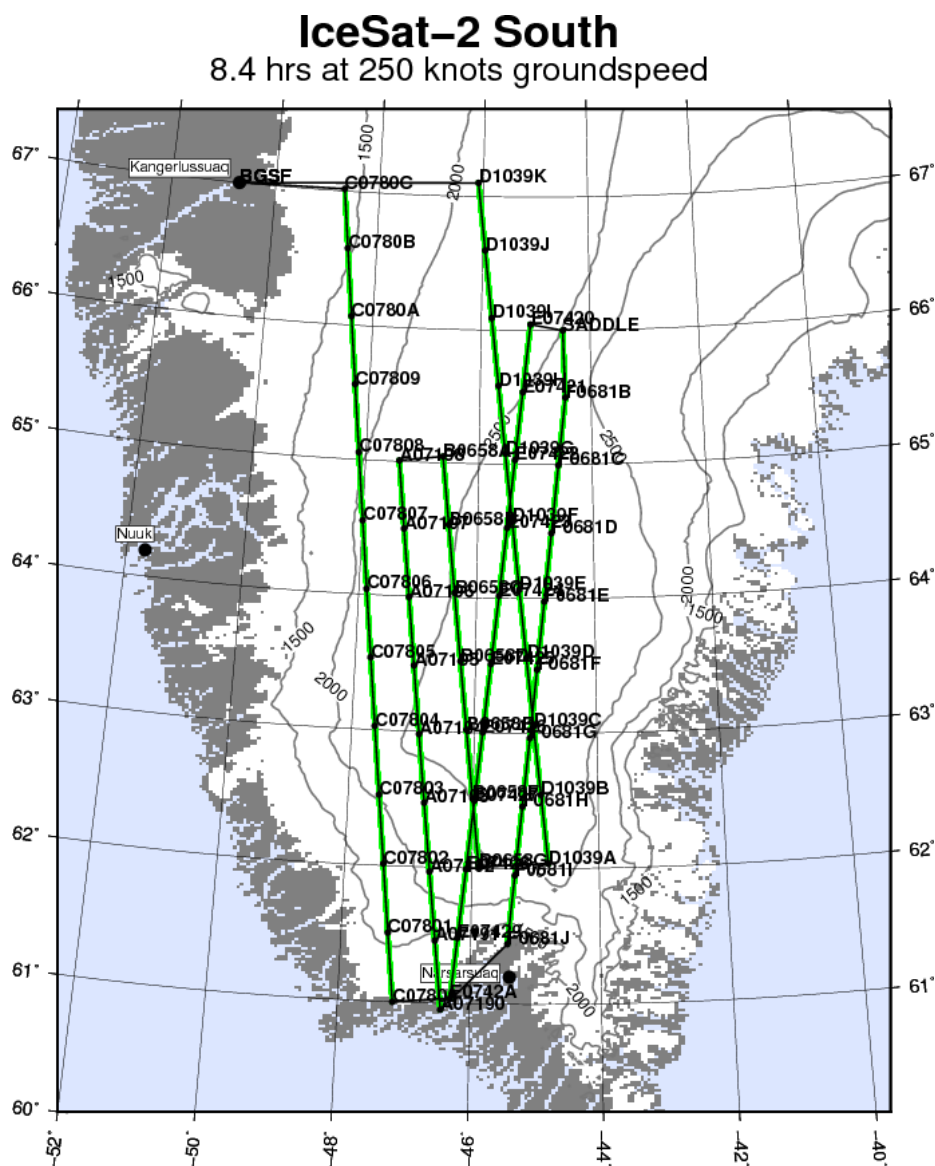
This mission is designed along IceSat-2 ground tracks to fill the gap between the southeastern and southwestern suites of missions. We sample a total of six IceSat-2 orbits, mixing left, nadir, and right beam pair overflights. We also overfly a firm compaction study site at point Saddle. For 2019 we replace three of the previously-flown lines with lower-latency tracks (occupied by IS-2 on 15, 16 and 19 May 2019).

**Flight Priority:** high (multi-year repeat flight)

**ICESat-2 Track:** C0780,E0742,F0681,A0719,B0658,D1039

**Last Flown:** 2018

**Remaining Design Issues:** replace any of the lines with lower-latency IS-2 tracks if available



# Land Ice – Southwest Coastal A / Kangerlussuaq

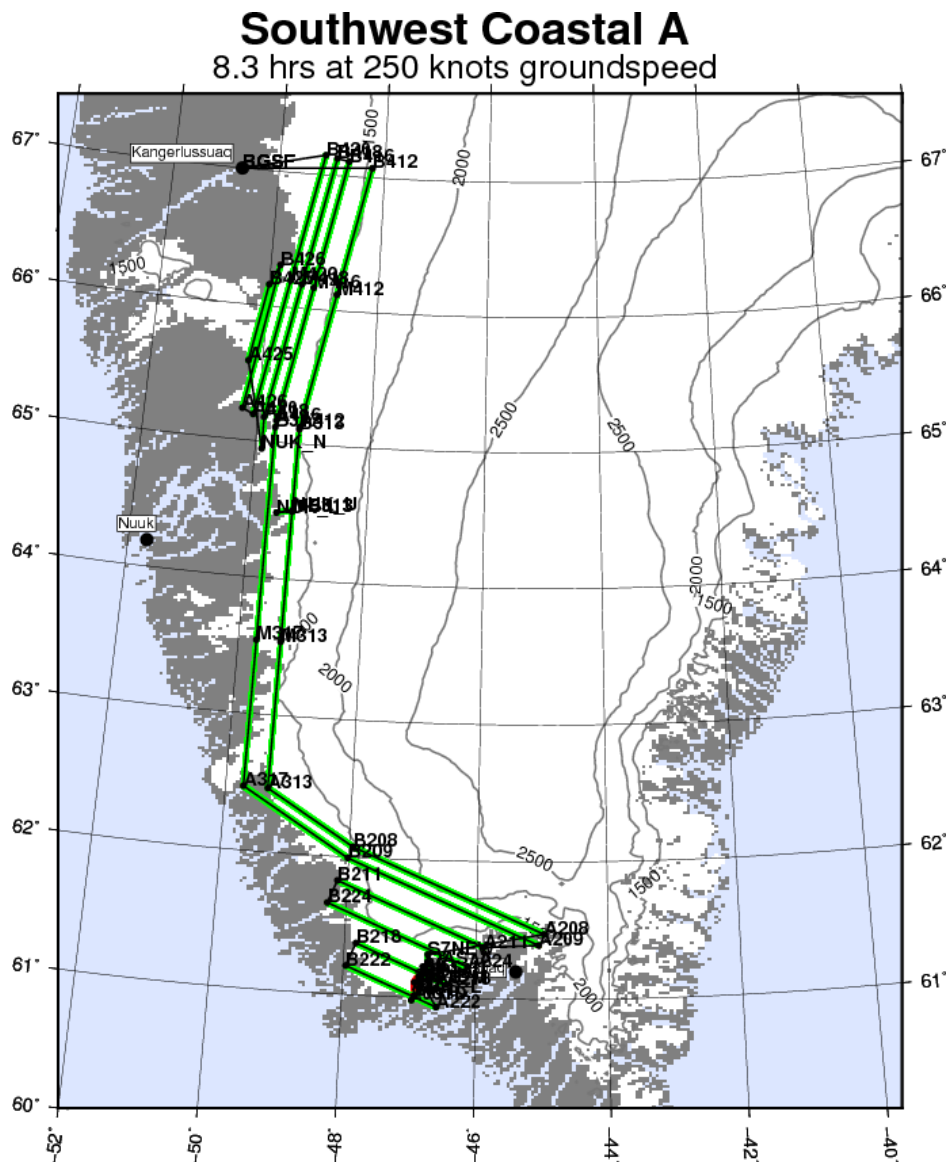
This mission is one of two (with Southwest Coastal B) designed to mirror the southeastern coast-parallel coverage in the southwest, along 2011 LVIS flight lines. This particular flight captures the lowest-altitude portion of this part of the ice sheet. We also overfly a total of six PROMICE sites.

**Flight Priority:** high (annual repeat flight prior to 2019)

**ICESat Track:** none

**Last Flown:** 2018

**Remaining Design Issues:** none



# Land Ice – Southwest Coastal B IS-2 / Kangerlussuaq

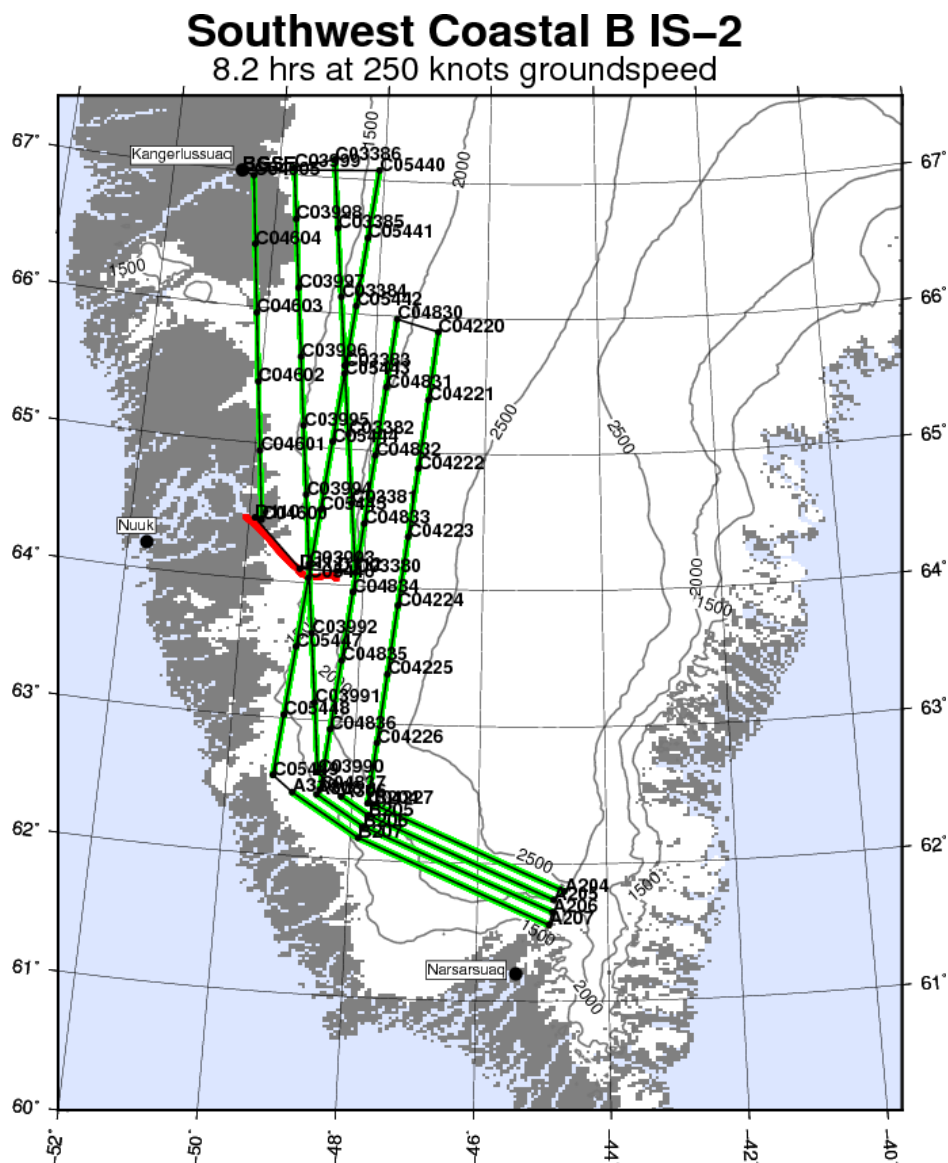
This mission is one of two (with Southwest Coastal A) designed to mirror the southeastern coast-parallel coverage in the southwest, along 2011 LVIS flight lines. This particular flight captures the higher-altitude portion of this part of the ice sheet. We also fly the Kangiata Nunaata Sermia glacier. For 2019 we replace the north-south-trending LVIS lines with low-latency ICESat-2 lines.

**Flight Priority:** high (multi-year repeat flight)

**ICESat-2 Tracks:** C0338,C0399,C0422,C0544,C0460,C0483

**Last Flown:** 2015

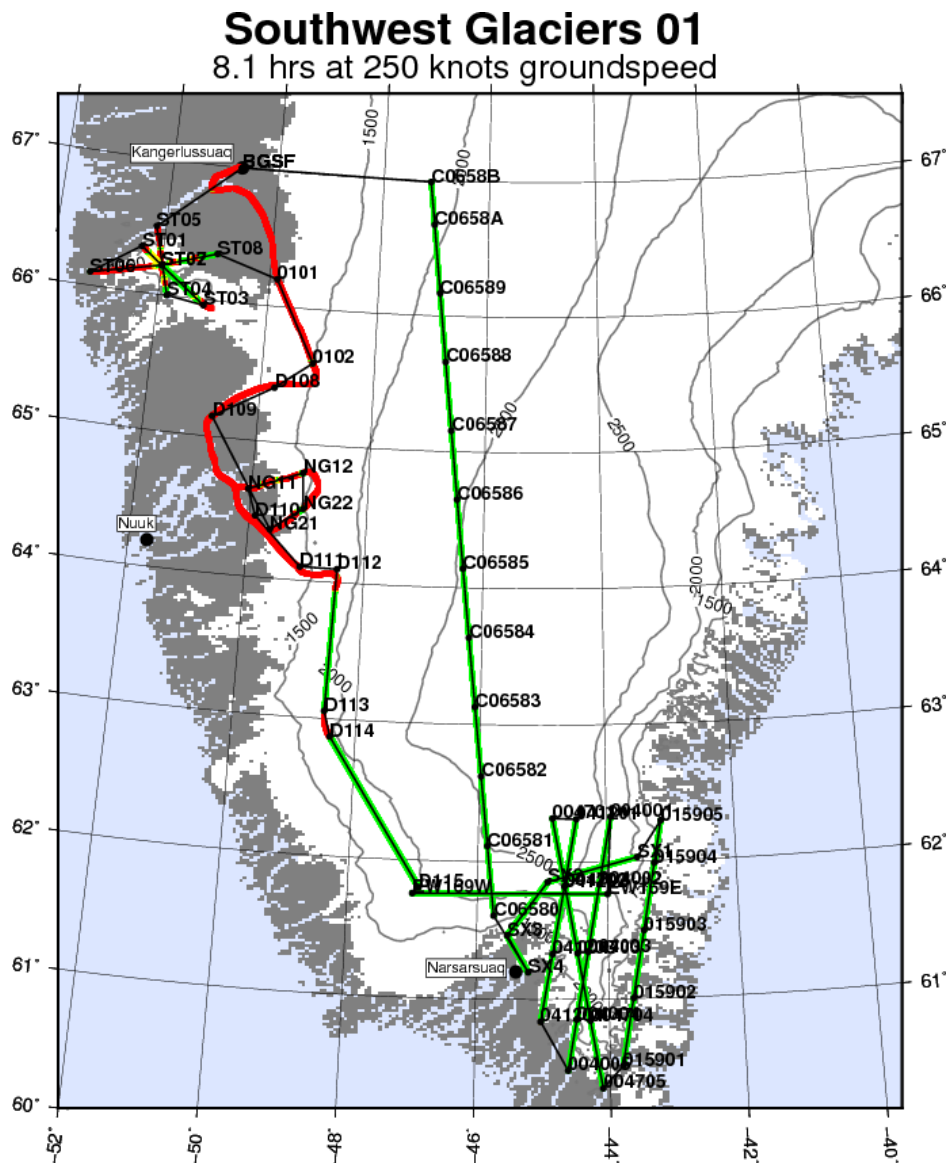
**Remaining Design Issues:** replace any IS-2 lines with lower-latency ones if available



This mission incorporates previously-flown lines over Sukkertoppen Ice Cap and over four glaciers near Nuuk, including Kangiata Nunaata Sermia, Tasersuaq, Narsap Sermia, and Akugdlersupasermia. We also re-fly a series of ICESat lines covering the southernmost lobe of the Greenland Ice Sheet. We return to Kangerlussuaq along a lengthy ICESat track over southern Greenland. For 2019 we replace an ICESat-1 line returning to Kangerlussuaq from the south with a low-latency ICESat-2 track.

**Satellite Track:** 0040,0412,0047,0159 (ICESat-1), C0658 (ICESat-2)

**Remaining Design Issues:** none



# Land Ice – ICESat-2 Sukkertoppen / Kangerlussuaq

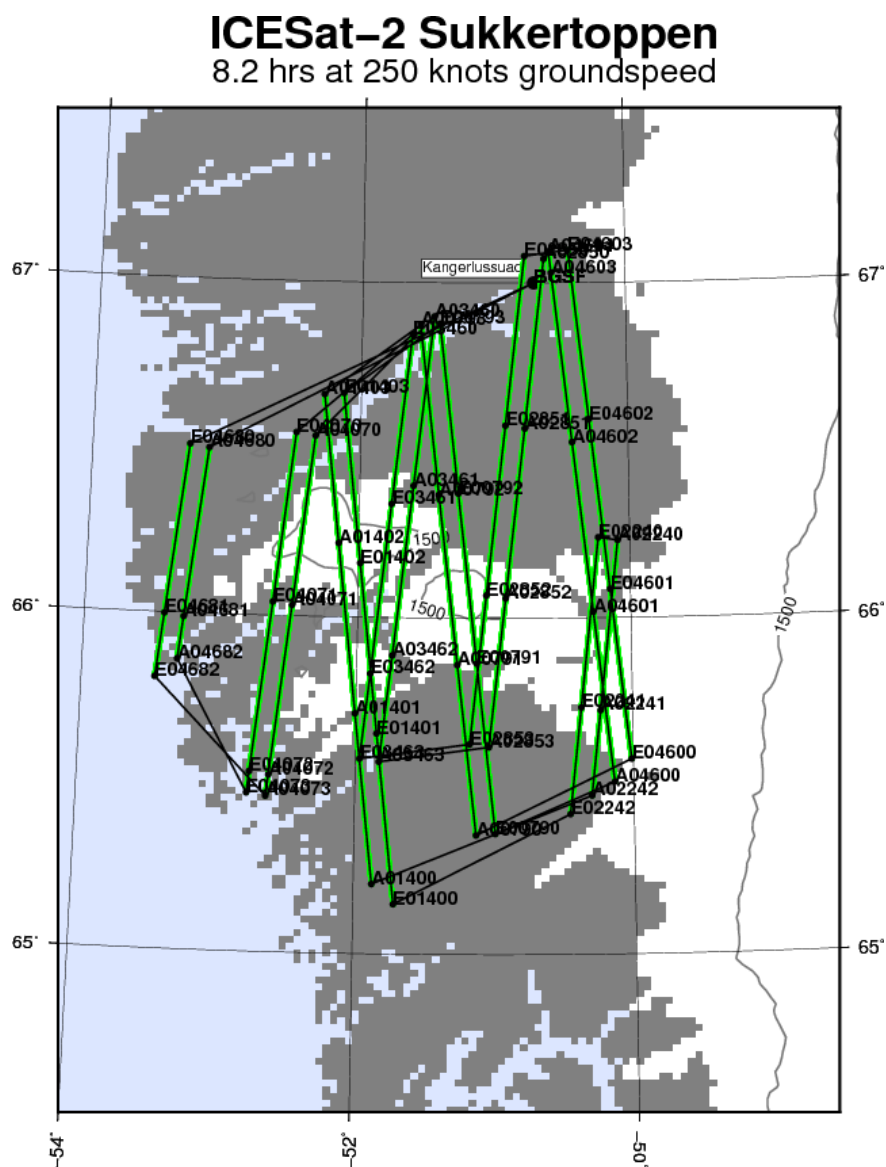
This is a new mission for 2019, designed to sample the left and right beam pairs of ICESat-2 over undulating bare rock and small ice caps in the vicinity of Sukkertoppen ice cap. The intention is to validate the geolocation of ICESat-2 footprints. The pattern of ICESat-2 ground tracks is nearly repeated, targeting the left beam pair on one pass and the right beam pair on the other. We validate range biases on the center beam pair during other missions.

**Flight Priority:** low

**ICESat-2 Tracks:** A0468,E0407,E0346,E0285,E0460,A0079,A0140,A0224,E0224,E0140,E0079,A0460,A0285,A0346,A0407,E0468

**Last Flown:** new flight

**Remaining Design Issues:** none



# Appendix A: Status of Community Flight Requests

Requests for flight line modifications from the OIB science team are incorporated into the flight lines, in an interactive manner with the team through telecons and the planning meeting. The status of requests from researchers without an institutional connection to OIB, which are by nature less interactive, are summarized below. The color code below is as follows: green=request explicitly addressed in flight plans, blue=request could not be addressed, red=request yet to be addressed

1. In 2018 Bamber et al requested crossing overflights of four bedrock features of interest. We accommodate their Site 1 in the high-priority Northeast Grid 05 Prime mission, Site 2 in the medium-priority Northeast Glaciers 02 mission, Site 3 in the medium-priority Southeast Flank 01 mission, and Site 4 in the high-priority West-Central Bed Gap 01 mission. None of these missions were flown in 2018, so we keep these modifications for 2019.
2. Chris Chambers et al requested several flight lines intended to improve bed mapping of the large basal valley in northern Greenland. Their requests are focused on three areas: (1) an upper tributary which may connect the valley with the upper NEGIS, (2) the upper part of the main valley, and (3) a lower NEGIS tributary which may connect with the main valley. We incorporate three of these lines, from area 2, in the East Glaciers 01 mission.
3. Chris Polashenski requested short (~10 km) north-south and east-west crossing lines over a field site in Elson Lagoon, near Barrow. The NS line was their higher priority. Recent deletion of the Fairbanks portion of the campaign makes this impossible.
4. Stefan Hendricks/AWI requested a cooperative flight along with their “IceBird” effort, which consists of a laser scanner, EM-Bird, and snow radar aboard a Basler. Following the rescheduling of the project after the December-January government shutdown, our respective schedules will not allow cooperative flying.
5. Jason Briner requested coverage over five sites in northern Greenland to support a drilling project. They are interested in radar data over the sites. Their primary site is Prudhoe Land, and their Hiawatha sites are probably the least important. The Prudhoe Land site is included in the Northwest Coastal A mission, and the Prudhoe Land, Hiawatha, and Victoria Land sites are incorporated into the ICESat-2 Peary Land mission. The Dronning Louise Land site is included in the North-Central Gap 03 mission.
6. The SnowEx project requested efforts ranging from a dedicated flight to a single flyover, working their experiment site at Trail Valley Creek near the Mackenzie River delta. Recent deletion of the Fairbanks portion of the campaign makes this impossible.
7. Melinda Webster requested that we incorporate flyovers of three SODA (Stratified Ocean Dynamics of the Arctic) moorings in the Beaufort Sea. Recent deletion of the Fairbanks portion of the campaign makes this impossible.
8. Tania Casal and Rene Forsberg requested two coordinated sea ice flights during their deployment to Station Nord during the second half of March. Post-shutdown schedule changes probably make coordinated flights with them impossible.
9. Robin Bell requested a slight modification to the Jak-Eqip-Store mission to overly a basal area of interest. The feature was overflowed during a turn on a previous flight of that mission, so we simply fly an exact repeat of that particular turn.
10. Larry Smith repeated his request from 2018 of overflights of hydrology sites in Inglefield Land, with a slight modification in the proglacial area. We fly this line in the North Bed Gap 01 flight.

11. PROMICE (Liam Colgan) requested another overflight of the “Q-Transect” in far southern Greenland. This is accommodated in the Southwest Coastal A flight.
12. Leuliette/Farrell/Connor request more Sentinel-3a/3b and CryoSat-2 underflights. We intend to work these in, as able, according to orbital geometry and timing of the respective spacecraft.
13. Overly requested a line connecting Thule/NEEM/Summit (and probably Thule/CC/NEEM/NGRIP/Summit). This requires several hours of flight time. A portion of it is in the Northeast Glaciers 02 mission.

# Appendix B: ICESat-2 Beam Patterns and OIB

The ICESat-2 ATLAS instrument emits 6 individual laser beams in a pattern fixed relative to the structure of the spacecraft. We refer to these 6 beams, when expressed in the frame of reference of the spacecraft itself (and NOT their positions on the earth's surface), as the “engineering beams”. The six beams are not identical – they are divided into “strong” and “weak” beams, three of each. Additionally two of the three “strong” beams are also known as TEP (Transmit Echo Path) beams, meaning that IceSat-2 records something similar to their start pulse waveforms. We also have a database known as the “reference ground track”, which are in fact the geodetic coordinates of the six beams along the surface of the earth. These are labeled with numbers 1, 2 and 3 designating, respectively, the left, center and right beam pairs, and by L and R within each pair designating the left or right beam. Thus the right beam of the center (nadir) beam pair is 2R, and the left beam of the right beam pair is 3L. For this discussion, the terms “left” and “right” are from the perspective of a person facing the direction of travel of the spacecraft.

Since the yaw attitude of the spacecraft is not fixed, the relationship between the six engineering beams and the six reference ground tracks are also not fixed, and we seek to understand how to map the engineering beams to the reference ground tracks in a simple and reliable manner. This is necessary because the 6 engineering beams are not identical to each other.

The six engineering beams are arranged in three pairs, with two near nadir, two at spacecraft left, and two at spacecraft right. The beams are labeled numerically 1-6. Each pair has one strong and one weak beam. The strong beams are the odd-numbered beams 1, 3 and 5, while the weak beams are the even-numbered beams 2, 4 and 6. The TEP beams are 1 and 3. The beam pairs are separated by ~3.3 km across-track, and the two beams in each pair are separated by ~90 m. But depending on the yaw attitude of the spacecraft, the relative locations on the ground of the strong and weak beams, and two TEP beams, varies.

For the reference ground tracks, the six beam paths (1L,1R,2L,2R,3L and 3R) are invariant with spacecraft attitude. Beam 2L, for instance, is always the left beam of the center beam pair, though beam 2L might correspond to different engineering beams depending on the spacecraft's yaw attitude. Figure B1 below depicts the reference ground track geometry for one ascending track near Summit Camp, Greenland.

For the purposes of ATM and OIB, we must identify reference ground tracks by single characters rather than the two-character 1L etc scheme, due to a number of different software limitations. So internally, we replace 1L with A, 1R with B, etc through 3R with F. For flight planning purposes, we also have three “virtual” reference ground tracks, X, Y and Z. Each corresponds to the centerline of a beam pair, with X for the left beam pair centerline, Y for the center pair, and Z for the right pair. This is in response to a recommendation from the OIB science team to fly the centerlines of the beam pairs in certain circumstances, rather than center the aircraft on specific individual beams. Figure B1 also shows the correspondence between the internal beam letters (A-F) in the reference ground track and the more generally-used two-character scheme.

For the spring 2019 Operation IceBridge deployment time frame, it is expected that the yaw orientation of ICESat-2 will be held to what is known as the “-X” orientation. In this orientation, the three strong beams lead the three weak beams along-track, the strong beams are the left beams of each pair, and the weak beams are the right beams of each pair. Furthermore, the TEP beams in this yaw orientation

correspond to beams 1L and 2L in the reference ground track. See Figure B2 below for a depiction of the engineering beam geometry for the -X spacecraft orientation.

Note that the yaw orientation of the spacecraft can be expected to change from time to time, roughly once every six months. Thus the mapping that follows is valid ONLY FOR JANUARY-MAY 2019 and MUST BE REVISITED for all subsequent time frames. The two colors in the table indicate that items highlighted in the same color remain in lockstep regardless of the spacecraft's yaw attitude, while items in different colors change in their relation to each other when yaw orientation changes. For instance, ref track ID 2L always corresponds to internal ref track letter C, and engineering beam 3 is always a strong beam with TEP. But the laser occupying ref track 2L is not always strong beam #3.

Ref track ID	Ref track letter (OIB internal)	Engineering beam #	Beam type	TEP
1L	A	1	strong	yes
1R	B	2	weak	no
2L	C	3	strong	yes
2R	D	4	weak	no
3L	E	5	strong	no
3R	F	6	weak	no

The table below identifies the geometric meaning of the “virtual” reference track letters X, Y and Z, which are the centerlines of the respective beam pairs. These are created (internal to ATM/OIB) for flight planning purposes because of a recommendation from the OIB science team that, in some cases, we place the aircraft not over a specific beam but over the center of a given beam pair. This is usually intended to maximize our chances of covering both beams of a pair with the ATM wide scanner (~250 m in width).

Virtual track letter (OIB internal)	Corresponds to beam pair centerline
X	Left / 1
Y	Center / 2
Z	Right / 3

# IceSat-2 at Greenland Summit

Red:A(1L), Green:B(1R), Blue:C(2L), Orange:D(2R), Magenta:E(3L), Cyan:F(3R)

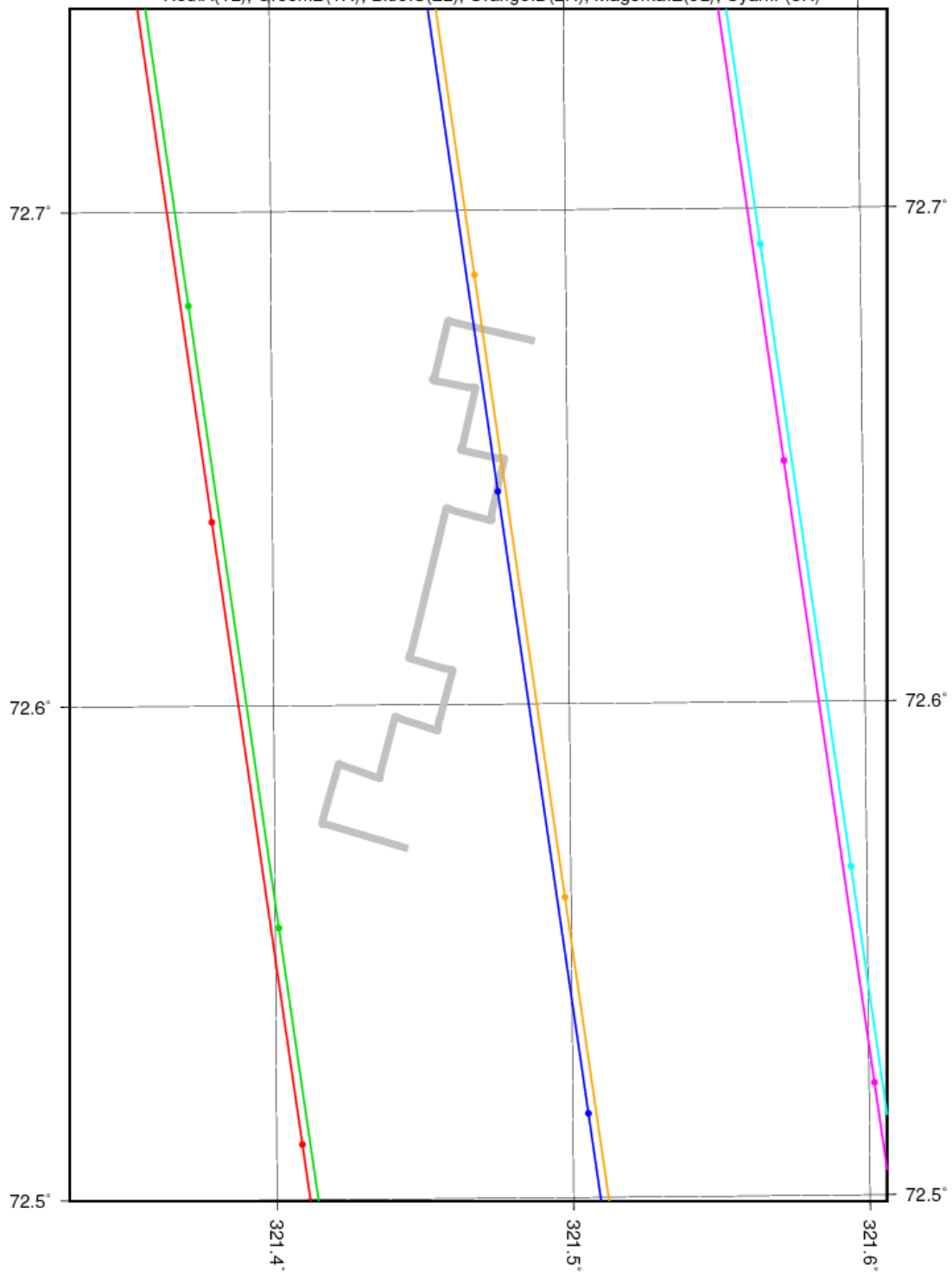


Figure B1. Ascending ICESat-2 reference ground tracks (ref orbit #0749) at Summit, Greenland.

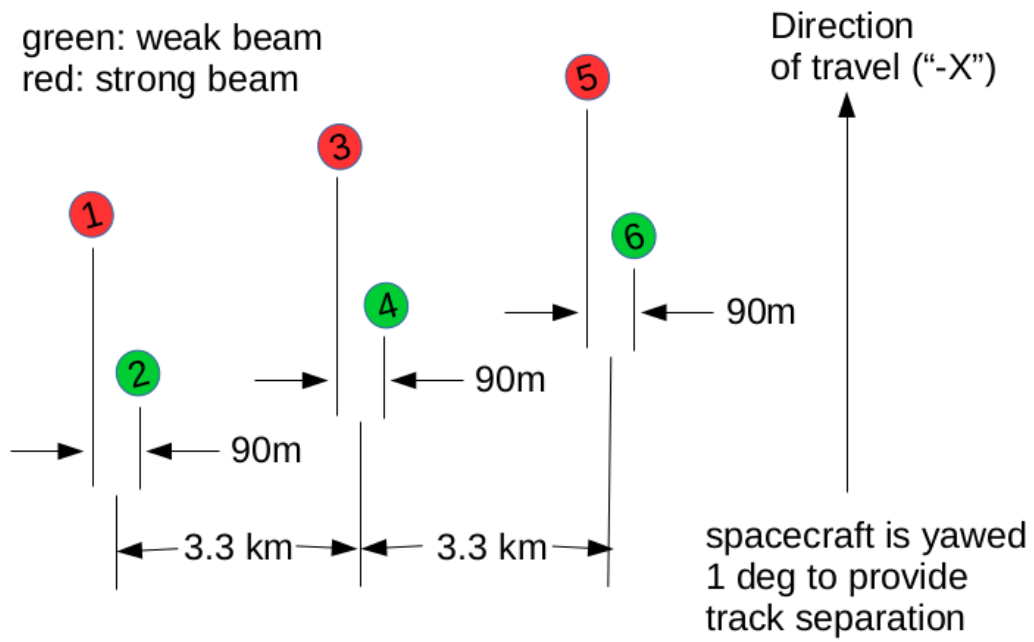


Figure B2. Spacecraft beam pattern for "-X" orientation.

# Appendix C: Sea ice drift corrections

For 2018 and 2019, a requirement arose from the OIB science team to apply “drift corrections” to some of our planned flight paths. These corrections apply to all sea ice missions that include a low-latency ICESat-2 component.

The purpose of the corrections is to modify our flight paths, according to the time differences between the expected time of our aircraft’s arrival at each of our waypoints and the overflight time of the ICESat-2 spacecraft, and according to the expected drift velocity of the sea ice. At each waypoint, the drift correction yields a position offset which can be applied in real-time as we fly. The result is that we improve the chance that our aircraft and the spacecraft measure the same swath of sea ice within a few hours, even as the ice itself drifts according to winds and currents.

An important component of the drift correction arises from the surface winds. Since the P-3 has real-time winds readily available to the flight crew and hence to the instrument team, we can use winds measured in-situ and in real time to inform the drift correction. Since we measure winds at altitude, while the surface winds are what is required, we will apply altitude-dependent scaling corrections to the wind speed as part of the drift correction algorithm.

Our plan for determining the drift corrections is as follows. When we initially enter the survey line, we will note the wind speed and direction at our altitude. If possible given visibility conditions and other factors, we will descend to as low as 500’ AGL and remain there for ~60 seconds to allow the air data measurements to stabilize, then note the wind speed and direction there, since we expect that winds at a lower altitude will better represent the surface winds than those measured at higher altitude.

Regardless of the altitude used to measure the winds, we will then enter these measurements into a software tool which will determine a velocity vector, representing our best estimate of the current sea ice drift rate and direction. For each waypoint in the flight plan, the software tool will calculate the time difference between our arrival at that waypoint and the spacecraft’s arrival over the flight line, and use the drift correction velocity vector to calculate a position offset vector. These position corrections will then be applied to every remaining waypoint in the flight plan. We will repeat the wind measurement and drift correction procedure any time we note significant changes in the measured wind speed and/or direction.

The above applies to our “straight-line” IS-2 sea ice underflights, but we also plan to perform multiple “walking racetrack” style flights, with the multiple racetrack passes intended to broaden our composite swath for all passes. This should maximize our odds of capturing the same ice observed by ICESat-2 in the presence of errors in knowledge of drift and in knowledge of ICESat-2 pointing. For these racetrack flights, we conduct a single drift correction for all waypoints based on the time difference for the first pass around the pattern. The later passes, offset by several hundred meters, must retain a fixed amount of overlap with the earlier passes and thus should not be displaced differently.

The technical details of the drift correction algorithm are beyond the scope of this document, but are available upon request.

# Appendix D: Design considerations for ICESat-2 sea ice missions

The IceBridge and ICESat-2 sea ice science team members have agreed that OIB should be prepared to fly as many as five dedicated ICESat-2 low-latency missions, in addition to the regular OIB sea ice survey missions. Three of these should be considered baseline-priority missions, and two as high-priority missions. We also hope to work low-latency IS-2 tracks into regular OIB missions as practical. But for the dedicated IS-2 missions, the design trade space is potentially enormous. Since these missions have to be designed close in time to the date on which they are to be flown (due to changing weather and orbital geometry and timing considerations), here we provide a “cookbook” for designing up to five of these missions.

For April 2019, low-latency ICESat-2 orbits are not ideally placed for operations from Thule during normal airport opening hours. The best available ground tracks, based on their timing, will be ascending ones, in the area north and northwest of Ellesmere Island.

Three of the five missions will be “walking-racetrack” style flights, intended to obtain very broad coverage over TEP beams A (“1L” to the IS-2 community) and C (“2L”). We place a single ~200 km pass over a drift-corrected, low-latency beam A and beam C flown in opposite directions (thus the “racetrack” analogy), then “walk” that racetrack pattern in a direction perpendicular to the ground track so that successive passes are offset to one or each side, depending on wind. The degree of offset should yield overlap of adjacent ATM wide-scan (T6) swaths of 15%. The racetracks should be flown at an altitude of 1000m, yielding a T6 swath of 500m and an overlap of 75m. Therefore the offset between adjacent flight lines should be 425m. We will perform a single discrete drift correction, using modeled surface winds obtained prior to takeoff, and calculated for the time elapsed between the spacecraft’s passage overhead and the time of our aircraft’s arrival on-site. Three of the five IS-2 dedicated sea ice flights should be these racetrack-style flights, with one placed around 100 km from the coast of the Canadian Arctic Archipelago, another placed several hundred km away from the coast, and a third roughly halfway between.

The racetrack pattern depends on winds. If the cross-track (relative to the IS-2 reference ground track) wind component is less than 3 knots, we drift-correct the A and C ground tracks according to modeled winds obtained prior to takeoff and our expected arrival time, and then offset the racetrack pattern 425m to the east, and then 425m to the west, for three circuits. If the cross-track wind component is greater than 3 knots and westerly, we drift-correct as above, then we further offset the reference tracks 50m west (upwind), offset the next pattern 425m to the east, and the third 850m to the east (walking the pattern downwind with time). If the winds are easterly and >3 knots cross-track, we do the reverse of the above. To account for differences in distance to and from Thule, we simply adjust the length of the racetrack legs accordingly.

The remaining two flights will be straight-line flights along TEP beam C/2L on a low-latency track, starting from the Canadian archipelago’s coast and going north as far as possible at 1000m altitude, then returning direct to Thule at high altitude. We will drift correct these waypoints in a continuous fashion, calculating the time elapsed at each waypoint between the spacecraft’s passage overhead and our arrival at the waypoint, and calculating the drift at each waypoint according to in-situ winds and those elapsed times.

Regarding priorities, the three baseline-priority flights will include two of the racetracks and one of the straight-line flights, with one of each making up the two high-priority flights.

# **Appendix E: WorldView / ICESat-2/ OIB coordination**

The OIB science team (and others) requested that OIB data collection over ICESat-2 lines, on Arctic sea ice, be coordinated with WorldView satellite imagery collection as well. This effort is complicated by the fact that, for OIB, the IS-2 underflight lines are planned just a few days prior to the flight. This schedule is driven primarily by uncertainty in weather forecasts – we plan the underflights only when we believe that we have a reasonable chance of actually executing them. In practice, this means that we most often plan IS-2 underflights 1-2 days prior.

Given that, our plan for accomplishing the WorldView coordination is as follows. On a given day of the OIB Arctic campaign when sea ice flights are possible (probably between 2 and 26 April 2019), we will consult weather forecast models and IS-2 orbit predictions, determining if any suitable coordinated sea ice underflights are likely to be successful two days hence (clear skies for both aircraft and spacecraft to see the surface). Between 1 and 3 OIB flight plans for that day will be generated, incorporating the low-latency IS-2 tracks. These flight plans, or their most relevant portions, will be sent via email to our WorldView targeting contacts (Steven Hak, [jhak@usgs.gov](mailto:jhak@usgs.gov)). Since we will be in-flight from roughly 1100 to 1900 UTC on these days, we will be able to send them only after we land, giving our WorldView contact(s) on the order of 36 hours to process the targeting requests.